THE JOURNAL of the Acoustical Society of America

• CONTENTS •

Acoustical Tables for Air and Sea Water . . . . . WILLIAM L. WOOLF 83

Estimation of Percentage Loss of Hearing . . . . . HOWARD A. CARTER 87

Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases . . . . . HOWARD C. HARDY 91

Acoustic Laboratory in the New RCA Laboratories . . . . . HARRY F. OLSON 96

Extension of the Doppler Principle to Discontinuous Periodic Effects . LIONEL FLEISCHMANN 103

Discussion of Acoustic Cells for Airplane Engine Test Buildings . . . . . DARIEL FITZROY 106

Physics Building Fund 113

Sound-Proof Airplane Motor Test Chambers . . . . . I. E. KATEL 114

Industrial Music and Morale . . . . . DAN D. HALPIN 116

Music as a Safety Factor . . . . . EDITH HOUGH 124

Attitudes Toward Types of Industrial Music . . . . . W. A. KERR 125

Programming Music for Industry . . . . . BEN SELVIN 131

Statistical Method in Determining the Effects of Music in Industry . . . R. L. CARDINELL 133

Letter to the Editor

On Subjective Tones . . . . . JOHN D. TRIMMER 136

Acoustical Society News 137

Current Publications on Acoustics . . . . . F. A. FIRESTONE 138

Book Review . . . . . HALLOWELL DAVIS 138

References to Contemporary Papers on Acoustics 139

Review of Acoustical Patents . . . . . ROBERT W. YOUNG 141

Vol. 15, No. 2 OCTOBER, 1943

THE JOURNAL
OF THE
ACOUSTICAL SOCIETY OF AMERICA

Volume 15 Number 2

OCTOBER • 1943

Acoustical Tables for Air and Sea Water

WILLIAM L. WOOLF
Stevens Institute of Technology, Hoboken, New Jersey
(Received July 10, 1943)

IN any sound wave in a non-changing medium there is a fixed relationship between the sound pressure, intensity level, particle velocity, and particle displacement at a given frequency. Therefore, if the condition of the medium is known, it only becomes necessary to determine any one of the above characteristics in order to predict the others.

The acoustical tables A for air, and W for sea water, reproduced herewith show the relationships among pressure level, sound pressure, intensity level, particle velocity, and the product of particle displacement and frequency in air and sea water under a given set of conditions, *viz.*, those in which $\rho c = 40$ c.g.s. units for Table A, and 150,500 c.g.s. units for Table W.

The tables are computed in steps of one decibel from 0 db to 194 db, the latter corresponding to a sound pressure of approximately 1 atmosphere. Although the tables are based on exponential relations, straight line interpolation may be employed without significant error to the nearest one-tenth of a decibel.

In addition to the nomenclature (see page 86), there are reproduced herewith equations and notes found useful at Stevens Institute of Technology, and believed to be of interest to students, engineers, and physicists who may use the tables.

In these tables db gives the "pressure level" which has been defined by the American Standards Association as follows: "The pressure level, in decibels, of a sound is twenty times the logarithm to the base ten of the ratio of the pressure P of this sound to the reference pressure P_0. Unless otherwise specified, the reference pressure is understood to be 0.0002 dyne per square centimeter." [1]

Also, db is the "intensity level" under the special case in which $\rho c = 40$ c.g.s. units in Table A, and 150,500 c.g.s. units in Table W. "The intensity level, in decibels, of a sound is ten times the logarithm to the base ten of the ratio of the intensity I of this sound, to the reference intensity I_0. Unless otherwise specified, the reference intensity I_0 (in air) shall be 10^{-16} watt per square centimeter." [1] The value of I_0 for air in c.g.s. units is 10^{-9}.

Since the American Standards Association has set up two standards for air which are consistent with each other only when $\rho c = 40$ (c.g.s. units),

[1] American Standards Association, J. Acous. Soc. Am. **14**, 88 (1942).

TABLE I.

Temp.		Pressure in cm mercury
C	F	
60	140	78.4
50	122	77.1
40	104	76.0
30	86	74.8
20	68	73.6
10	50	72.2
0	32	71.0
−10	14	69.6
−20	−4	68.3

Temperature-pressure combinations in dry air for $\rho c = 40$ (c.g.s. units).

TABLE II.

Altitude in ft. above sea level	Pressure in cm of mercury
0	76.0
500	74.6
1000	73.2
2000	70.7
3000	68.0
4000	65.6
5000	63.2
6000	60.9
8000	56.5
10000	52.3
12000	48.4
14000	44.7

At 0°C and 76 cm of mercury, $\rho c = 42.8$.
At 20°C and 76 cm of mercury, $\rho c = 41.3$.
If the latter condition exists at sea level, ρc will have a value of 40 at an altitude of 592 ft. above sea level.

this value has been used in computing values of I, v, and yf in Table A. For air of any given composition, ρc varies directly as the pressure, inversely as the square root of the absolute temperature; and for dry air, is equal to

$$42.8(273/T_c)^{\frac{1}{2}} \times H/76.$$

Table I shows various values of temperature and pressure combinations in air which give a value of $\rho c = 40$.

ALTITUDE

The atmospheric pressure and therefore the value of ρc varies with altitude, the relation of altitude to pressure being shown in Table II.

HUMIDITY

The above discussion refers to dry air. Water vapor in the air affects both ρ and c slightly. In any medium $c = (E/\rho)^{\frac{1}{2}}$. In dry air this becomes $c = (\gamma P_s/\rho)^{\frac{1}{2}}$ and $\rho c = (\rho \gamma P_s)^{\frac{1}{2}}$. That is, the product ρc for any given static pressure varies as the square root of the density and the square root of the ratio of the specific heats. When water vapor is introduced into dry air the density is decreased, water vapor being lighter than air, the ratio of the molecular weights being 1.605 to 1.0. The ratio of the specific heats in moist air varies from the specific heats in dry air in accordance with the formula: $\gamma_{ma} = \gamma_{da} - 0.1e/P_s$. The vapor pressure e increases as the temperature and relative humidity increase, and therefore γ_{ma} decreases. If the moisture content is constant and the pressure of the dry air is reduced, as at high altitudes, γ_{ma} will also decrease. Hence the effect of water vapor in decreasing ρc is greatest at high altitudes. Under the extreme conditions of saturation and high temperatures such as 120°F and high elevations such as 5000 ft., the ratio of ρc for the above conditions to that of ρc for dry air at the same temperature and elevation is 0.975. In decibels, this is 10 log 0.975 = 0.11 db. For most practical purposes, therefore, the influence of moisture on ρc may be ignored.

PARTICLE DISPLACEMENT AND VELOCITY

The particle velocity depends only on the pressure and ρc. The particle displacement, however, depends also on the frequency. The product of displacement and frequency is listed in the tables. The values v and yf may be computed from any of the relations shown under Equations, and y may be found by dividing yf by f.

R.M.S. VALUES

In the db formulas, the values of P, P_0, I, I_0, etc., may be either r.m.s. or peak as long as they are used consistently. The reference pressure, however, is given as 0.0002 dyne/cm², effective, or r.m.s. In the equation for intensity in terms of P^2, r.m.s. values for P *must* be used. Also, any equation derived from this involving I must be used with r.m.s. values. In a sine wave, the peak pressure is equal to the effective or r.m.s. pressure times $\sqrt{2}$.

RELATION OF WATER COMPUTATIONS TO THOSE IN AIR

It is interesting to note that the values of pressure level in Table W are identical with those in Table A; also that definite relations exist between the intensity, velocity, and yf columns of the two tables.

The intensity values tabulated in the third column of Table W are the same as those in Table A shifted upward 35.75 db, that is, to a position opposite a pressure level which is 35.75 db lower. This value comes from the expression

$$10 \log \frac{(\rho c) \text{ water}}{(\rho c) \text{ air}} = 10 \log \frac{150{,}500}{40} = 35.75.$$

In sea water, the velocity of sound c in cm per sec. is given by the formula

$$c = 150{,}500 + 176(F-60) - 1.34(F-60)^2.$$

The value of ρ is approximately unity. . . . It will be seen that for temperatures between 30°F and 90°F this value changes only 0.23 db, so for practical purposes it is usually considered to be constant. The last term should be neglected as it affects the value of ρc probably less than changes in the density ρ produced by variations in the pressure, temperature, and salinity of the water, and these have been neglected.

The values in Table W of the velocity v and of the product of the frequency times the displacement, yf, are likewise the same as those in Table A shifted upward 71.5, which is just twice the db shift for the intensity values, or

$$20 \log \frac{(\rho c) \text{ water}}{(\rho c) \text{ air}}.$$

For example, for a pressure of 96 db the intensity value for air is read opposite 96 as 39.8×10^{-8}. Similarly, the intensity value for water at 96 db is read from Table W as 105.8×10^{-12}. This latter

TABLE A. Acoustic table for air.

db = pressure level—decibels
P = r.m.s. sound pressure—dynes/cm²
I = intensity level—watts/cm²
v = r.m.s. particle velocity—cm/sec.
y = r.m.s. particle displacement—cm
f = frequency—cycles/sec.
ρ = density—g/cm³
c = velocity of sound—cm/sec.
ρc = 40 c.g.s. units

db	P	I	v	yf
Values for intervals of 20 db. Each figure must be multiplied by 10^n where "n" is given below for each interval				
0	2.000	1.000	5.000	7.958
1	2.244	1.259	5.610	8.929
2	2.518	1.585	6.295	10.02
3	2.825	1.995	7.063	11.24
4	3.170	2.512	7.924	12.61
5	3.557	3.162	8.891	14.15
6	3.991	3.981	9.976	15.88
7	4.477	5.012	11.19	17.82
8	5.024	6.310	12.56	19.99
9	5.637	7.943	14.09	22.43
10	6.325	10.00	15.81	25.16
11	7.096	12.59	17.74	28.24
12	7.962	15.85	19.91	31.68
13	8.934	19.95	22.33	35.55
14	10.02	25.12	25.06	39.88
15	11.25	31.62	28.12	44.75
16	12.62	39.81	31.55	50.21
17	14.16	50.12	35.40	56.34
18	15.89	63.10	39.72	63.21
19	17.83	79.43	44.56	70.92
20	2.000	1.000	5.000	7.958
		Values of n		
0–19	−4	−16	−6	−7
20–39	−3	−14	−5	−6
40–59	−2	−12	−4	−5
60–79	−1	−10	−3	−4
80–99	0	−8	−2	−3
100–119	1	−6	−1	−2
120–139	2	−4	0	−1
140–159	3	−2	1	0
160–179	4	0	2	1
180–199*	5	2	3	2

* The equations from which this table was computed were derived on the assumption that the sound pressures are small in comparison with atmospheric pressure. Experiments have shown that the tabulated values may be used for approximate calculations up to about 185 db, the errors being less than those normally suffered in making sound measurements. Between 185 db and 194 db the resultant errors may be of a magnitude to require consideration. Above 194 db the equations are quite inapplicable because they require minimum resultant pressures below absolute zero.

TABLE W. Acoustic table for sea water.

db = pressure level—decibels
P = r.m.s. sound pressure—dynes/cm²
I = intensity level—watts/cm²
v = r.m.s. particle velocity—cm/sec.
y = r.m.s. particle displacement—cm
f = frequency—cycles/sec.
ρ = density of sea water—g/cm³ = 1 (approx.)
c = velocity of sound in sea water—cm/sec.
ρc = 150,500 c.g.s. units

db	P	I	v	yf
Values for intervals of 20 db. Each figure must be multiplied by 10^n where "n" is given below for each interval				
0	2.000	2.658	1.329	2.115
1	2.244	3.346	1.491	2.373
2	2.518	4.212	1.673	2.663
3	2.825	5.303	1.877	2.988
4	3.170	6.676	2.106	3.352
5	3.557	8.405	2.363	3.761
6	3.991	10.58	2.652	4.220
7	4.477	13.32	2.975	4.735
8	5.024	16.77	3.338	5.313
9	5.637	21.11	3.745	5.961
10	6.325	26.58	4.202	6.688
11	7.096	33.46	4.715	7.504
12	7.962	42.12	5.290	8.420
13	8.934	53.03	5.936	9.447
14	10.02	66.76	6.660	10.60
15	11.25	84.05	7.473	11.89
16	12.62	105.8	8.385	13.34
17	14.16	133.2	9.408	14.97
18	15.89	167.7	10.56	16.80
19	17.83	211.1	11.84	18.85
20	2.000	2.658	1.329	2.115
		Values of n		
0–19	−4	−20	−9	−10
20–39	−3	−18	−8	−9
40–59	−2	−16	−7	−8
60–79	−1	−14	−6	−7
80–99	0	−12	−5	−6
100–119	1	−10	−4	−5
120–139	2	−8	−3	−4
140–159	3	−6	−2	−3
160–179	4	−4	−1	−2
180–199	5	−2	0	−1

value is the same as one reads in Table A opposite the db value of 96−35.75, or 60.25. Similarly, the velocity for this same pressure level is 0.315 cm/sec. for air, and 8.38×10^{-5} cm/sec. for water. The latter value can also be found opposite the pressure level 96−71.5, or 24.5 db, in Table A.

The relationship between the yf's in the two tables is identical with that between the two velocities.

Thus, while Table A is computed for air and Table W for sea water, if one employs the above relationships he may use either table for both air and water.

NOMENCLATURE

Symbol	Name	Units
db	Pressure level	decibels
P	Sound pressure	dynes/cm²
I	Sound intensity	watts/cm²
v	Particle velocity	cm/sec.
y	Particle displacement	cm
f	Frequency	c.p.s.
ρ	Density of medium	g/cm³
c	Sound velocity in medium	cm/sec.
P_0	Reference pressure	dynes/cm²
I_0	Reference intensity	watts/cm²
v_0	Reference particle velocity	cm/sec.
$(yf)_0$	Reference frequency displacement product	cm×c.p.s.
P_s	Static pressure	dynes/cm²
H	Static pressure in centimeters of mercury	cm
e	Partial pressure of water vapor in air (vapor pressure)	dynes/cm²
γ	Ratio of specific heat at constant pressure to specific heat at constant volume for the medium	—
γ_{da}	Ratio of specific heats for dry air	—
γ_{ma}	Ratio of specific heats for moist air	—
E	Elastic modulus	dynes/cm²
T_c	Absolute temperature	°C absolute
F	Temperature	°F
C	Temperature	°C
c.g.s.	Centimeter-gram-second	
r.m.s.	Root-mean-square	

EQUATIONS

db $=20\log_{10} P/P_0$ (basic definition of db valid for all values of ρc),

db $=20\log_{10} P/P_0=10\log_{10} I/I_0=20\log_{10} v/v_0$ $=20\log_{10}(yf)/(yf)_0$ when $\rho c=40$ (c.g.s. units) for Table A, and 150,500 (c.g.s. units) for Table W,

$$I=(P^2_{\text{rms}}/\rho c)\times10^{-7}=P_{\text{rms}}v_{\text{rms}}\times10^{-7}=v^2_{\text{rms}}\rho c\times10^{-7},$$

$$P=v\rho c=2\pi\rho cyf=(I\rho c\times10^7)^{\frac{1}{2}}=(I/v)\times10^7,$$

$$v=P/\rho c=2\pi yf=(I/P)\times10^7,$$

$$yf=P/2\pi\rho c=v/2\pi=(I/2\pi P)\times10^7,$$

$c=(E/\rho)^{\frac{1}{2}}$ in any medium $=(\gamma P_s/\rho)^{\frac{1}{2}}$ in air, and $=[150{,}500+176\,(F-60)-1.34\,(F-60)^2]$ in sea water.

For dry air, $\rho c=42.8(273/T_c)^{\frac{1}{2}}\times H/76$; and for sea water since ρ is unity for all practical purposes, $\rho c=c$ as given for sea water above.

For moist air, $\gamma_{ma}=\gamma_{da}-0.1\,e/P_s$.

REFERENCE VALUES

Air

$P_0=2\times10^{-4}$ dyne/cm²

$*I_0=10^{-16}$ watt/cm²

$*v_0=5\times10^{-6}$ cm/sec.

$*(yf)_0=7.95775\times10^{-7}$ cm×c.p.s.

* when $\rho c=40$ (c.g.s. units)

Sea Water

$P_0=2\times10^{-4}$ dyne/cm²

$\dagger I_0=2.6578073\times10^{-20}$ watt/cm²

$\dagger v_0=1.32890\times10^{-9}$ cm/sec.

$\dagger(yf)_0=2.11502\times10^{-10}$ cm×c.p.s.

† when $\rho c=150{,}500$ (c.g.s. units)

Estimation of Percentage Loss of Hearing

HOWARD A. CARTER
Council on Physical Therapy of the American Medical Association, Chicago, Illinois
(Received May 15, 1943)

FOUR years ago the Consultants on Audiometers and Hearing Aids of the Council on Physical Therapy of the American Medical Association were asked to help formulate a method for estimating the percentage loss of hearing for medico-legal cases. It was pointed out to the consultants that a uniform, authorized method for estimating percentage loss of hearing was sorely needed by physicians associated with insurance companies, compensation commissions, rehabilitation bureaus, disability adjustment boards and courts of law. After careful study of the existing methods, the consultants aimed at the following requirements for the new method: (1) Easily understood; (2) easily and quickly worked out; (3) free of complicated mathematical calculations; (4) easily interpreted before any jury; (5) for both ears jointly considered as single hearing unit; (6) based on air-conduction acuity as measured by a standardized audiometer; (7) weighted to give preference to frequency ranges of the spoken voice; and (8) based on the best available acoustical and scientific evidence.

Many methods were reviewed, some were improved and revised. The information obtained through the study of the several methods was valuable and here and there bits of information were picked out and used in the method finally adopted. The method is intended to serve as a recognized basis for estimating the percentage loss of hearing for the average industrial case. It is not intended to determine the compensation which might be finally allowed to a particular claimant. This is the function of the court. The method adopted has been endorsed by the Council on Physical Therapy and the Section on Laryngology, Otology, and Rhinology at the Annual Session of the American Medical Association in 1942 and by the House of Delegates at its annual meeting in Atlantic City in June of the same year.

TABLE I. Kessler's table. Based on the fact that schedules of most states allow an average of about 40 percent total terminal disability for complete deafness. (Reference 1.)

Each ear	No hearing with loss of bone conduction, percent	No hearing with bone conduction, percent	1/40 percent	5/40 percent	10/40 percent	20/40 percent
No hearing with loss of bone conduction	40	35	30	25	20	10
No hearing with bone conduction	35	30	25	20	15	10
Spoken voice:						
1/40	30	25	20	15	12	7
5/40	25	20	15	12	8	5
10/40	20	15	12	10	7	5
20/40	10	10	7	5	5	0

OTHER METHODS THAT HAVE BEEN EMPLOYED

(a) Army, Navy and Veterans' Administration Methods

At the time of Pearl Harbor, the medical corps of the services were using the conversational voice test. The registrant or inductee is placed twenty feet distant from the examining physician and directed to repeat promptly words spoken. If he cannot hear the words at twenty feet the physician approaches foot by foot using the same tone of voice until the words are repeated correctly. The examinee does not see the lips of the physician. Each ear is tested separately while closing the other ear by pressing the tragus firmly against the meatus. If the registrant can hear the words at 20 feet he is given a rating of 20/20 which indicates normal hearing. If he hears the words at 10 feet it is called 10/20 which indicates partial hearing, and 5 feet would be 5/20 indicating that the registrant hears the words at 5 feet which should be heard at 20 feet. The Navy is less severe, requiring the registrant to hear the words repeated at a distance of 15 feet for normal hearing. This is a quick and ready way of testing the hearing of inductees. The use of audiometers, watch test, or tuning forks would consume too much time. Those inductees found to be deficient in hearing by the spoken voice method are tested by the more precise methods, including the audiometric test. No effort is made whatsoever in these tests to evaluate the percentage loss of hearing. In fact, the Army, the Navy, and the Veterans' Administration have never claimed that they do.

TABLE II. Fowler's chart for estimating percentage loss of hearing.*

Hearing level (averagedb loss) in worse ear	Hearing level (average decibel loss) in better ear											
	0	10	20	30	40	50	60	70	80	90	100	Total
0												
10												
20		6%	10%									
30		7%	11%	15%								
40		8%	12%	17%	20%							
50		9%	13%	20%	22%	25%						
60	5%	10%	14%	22%	25%	30%	35%					
70	10%	11%	15%	25%	30%	35%	40%	45%				
80	10%	12%	16%	25%	30%	35%	45%	50%	55%			
90	10%	13%	17%	25%	30%	35%	45%	55%	60%	65%		
100	10%	14%	18%	25%	30%	35%	45%	55%	65%	75%	75%	
Total	10%	15%	20%	25%	30%	35%	45%	55%	65%	75%	80%	85%

* E. P. Fowler, Jr., Editor, *Loose Leaf Medicine of the Ear* (Thos. Nelson and Sons, New York, 1939), p. 419.

TABLE III. Fowler's table for measuring percentage capacity for hearing. (Reference 3, p. 375.)

Weighted db loss—(worse ear)	Weighted db loss—(better ear)											Total deafness for speech
	0	10	20	30	40	50	60	70	80	90	100	
0	0%	0	1	5	9	14	20	27	35	44	54	63
10	0	2	3	4	5	6	7	8	9	10	11	
20	1	3	9	12	14	15	16	17	18	19	20	
30	2	4	12	20	24	27	29	30	31	32	33	
40	3	5	14	24	35	40	44	47	49	50	51	
50	4	6	15	27	40	54	59	63	66	68	69	
60	5	7	16	29	44	59	71	76	80	83	85	
70	6	8	17	30	47	63	76	84	88	91	93	
80	7	9	18	31	49	66	80	88	93	96	97	
90	8	10	19	32	50	68	83	91	96	98	99	
Total 100	9%	11	20	33	51	69	85	93	97	99	100%	

Percentage loss of capacity

(b) Kessler Method

In the method as outlined in "Accidental Injuries" [1] by Henry H. Kessler, the conversational voice test is at 20 feet. However, the ratio is made 20/40 for satisfactory conversational hearing. Table I is a table used to determine percentage loss. This method gives the percentage loss of hearing for the two ears as a single hearing unit.

(c) The Western Electric Method[2]

The audiometer is used in this method for

[1] Henry H. Kessler, *Accidental Injuries* (Lea and Febiger, Philadelphia, 1941), second edition.

[2] H. Fletcher, *Speech and Hearing* (D. Van Nostrand Company, Inc., New York, 1939), third edition.

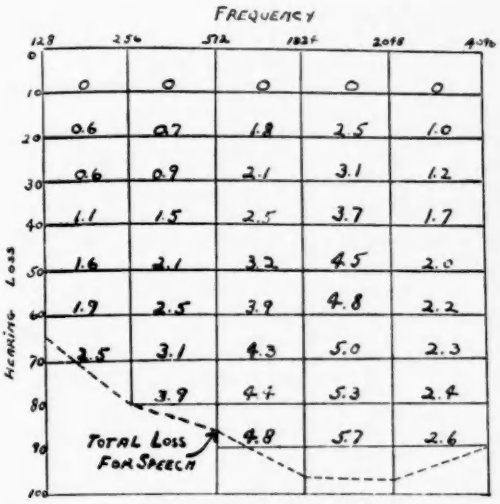


FIG. 1. Sabine's table for computing loss of useful hearing (reference 4).

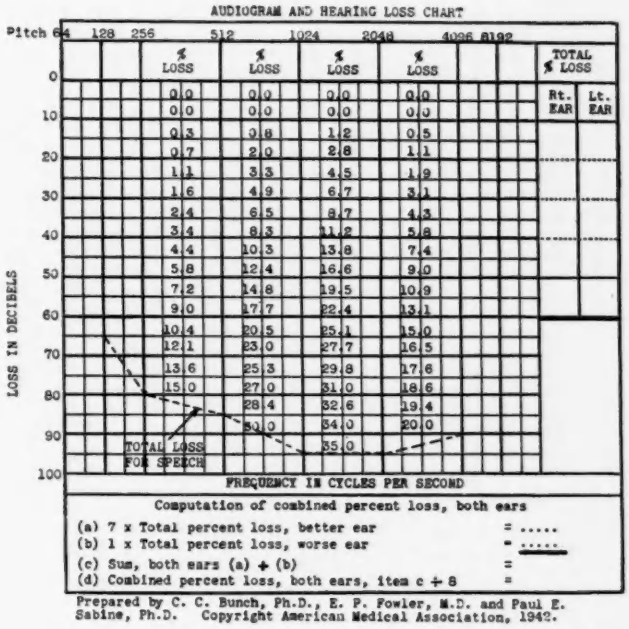

AUDIOGRAM AND HEARING LOSS CHART
Pitch 64 128 256 512 1024 2048 4096 8192
% LOSS
TOTAL % LOSS
Rt. EAR
Lt. EAR
LOSS IN DECIBELS
TOTAL LOSS FOR SPEECH
FREQUENCY IN CYCLES PER SECOND
Computation of combined percent loss, both ears
(a) 7 x Total percent loss, better ear
(b) 1 x Total percent loss, worse ear
(c) Sum, both ears (a) + (b)
(d) Combined percent loss, both ears, item c ÷ 8
Prepared by C. C. Bunch, Ph.D., E. P. Fowler, M.D. and Paul E. Sabine, Ph.D. Copyright American Medical Association, 1942.

FIG. 2. Audiogram and hearing loss chart (reference 5).

collecting hearing loss data in decibels and, by a formula, converts them into percentage loss of speech. The average decibel loss for frequencies 512, 1024, and 2048 is multiplied by a factor 0.8 to obtain the percentage figure for one ear only. The Maico and Sonotone methods are essentially the same. These methods determine the percentage loss for one ear at a time, but do not make any effort to combine the two percentage readings.

(d) The Fowler Method[3]

This method utilizes the audiometer to obtain the hearing loss data, and Tables II and III indicate how the audiometric data are used to determine the percentage loss of hearing for the individual.

(e) The Sabine Method[4]

In this method, the audiogram as measured by a standard audiometer is plotted on the chart shown in Fig. 1. This is the ordinary audiometric chart, on which the percentages of hearing pertaining to the various portions of the auditory field are indicated. The total percentage loss corresponding to any audiogram is the sum of the percentages in the spaces above the audiogram. The percentages shown in Fig. 1 are based on data on minimum perceptible differences of pitch and intensity given in Fletcher's *Speech and Hearing*.[2] Total percentage loss of hearing, both ears considered, is the weighted average of the losses for the two ears, with a weighting factor of 8 to 1 as between the better and worse ears.

(f) The Council Method[5]

The audiogram and hearing loss chart formulated by the Council on Physical Therapy is shown on Fig. 2. Here we have the usual audiogram chart, on which are shown the percentages of useful hearing to be assigned to each of the four octaves that are accepted as being essential to the interpretation of speech. These percentages are taken in part from the values given in Fig. 1 with modifications suggested by the Tables II and III, and further modifications, which, in the opinion of the members of the Committee on

[3] E. P. Fowler, J. Acous. Soc. Am. **13**, 373 (1942); Arch. Otol. **36**, 874–890 (1942).

[4] Paul Sabine, Trans. Am. Acad. Ophthalmol. and Otolaryngol. **46**, 179–187 (March–April, 1942).

[5] J. Am. Med. Assn. **119**, 1108–1109 (1942).

Audiometers and Hearing Aids, would bring them into line with clinical findings. Further modifications were based on reports of investigations by V. O. Knudsen, E. P. Fowler, Harvey Fletcher, J. C. Steinberg, and M. B. Gardner.

The line for zero loss of hearing is the average minimum threshold for normal ears. The curve for total loss of hearing for speech is taken from a paper by the late Dr. C. C. Bunch.[6] An audiometric reading of 10 db from the normal hearing zero loss line is not considered as constituting a loss of useful hearing for speech.

When using the chart for evaluating percentage loss of hearing, the procedure is as follows:

On a standardized audiometer, measure hearing losses at the different frequencies for each ear and plot in the usual manner. Successive points are connected by straight ruled lines. The percentage loss to be assigned to each octave interval is the figure in the space immediately above the straight line drawn in that octave. (When two or more spaces are intersected, the average of the figures in the intersected spaces is to be taken.) The figures for the four octaves for each ear are set down in their respective columns headed Right Ear and Left Ear at the right of the chart. The sum of the figures in the column headed Right Ear is the total percentage loss of hearing for the right ear, and similarly for the left ear. Combined hearing loss for both ears is computed as indicated at the bottom of the chart. The weighting of percentage loss shown by the better ear as compared with that by the worse ear of 7 to 1 represents the composite judgment of the committee based on both clinical experience and practical considerations. The percentage loss of hearing is the average of the losses for the two ears taken separately weighted in the ratio of 7 to 1.

The foregoing is recommended as a tentative standard procedure based on the present knowledge of the relation between the audiometrically measured acuity of hearing and the ability to interpret direct speech in a familiar language. The Council and its group of consultants welcome comments on the method.

[6] C. C. Bunch, Ann. Otol. Rhinol. Laryngol. **49**, 359–367 (1940).

Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases*

HOWARD C. HARDY
Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pennsylvania
(Received April 27, 1943)

The empirical Pielemeier equation used for measuring the absorption of sound in gases is derived from theoretical consideration of the principles of the Pierce interferometer and the quartz oscillator. A more complete explanation of the effect of sound resonance on the oscillator is given. The criteria for accurate measurement of the absorption coefficients in gases are set up and verified by experiment.

THE Pierce ultrasonic interferometer has been used by many investigators for the measurement of the velocity of sound in gases. The decrease in magnitude of the peaks in the plate current with increase of distance of the reflector is well known. Some investigators[1–5] have attempted to interpret this decrease in such a way as to calculate the absorption coefficients at high frequencies. Pielemeier[1] was the first to have observed an approximate logarithmic decrease in peak-to-trough height when the interaction of the sound wave on the crystal was small, and he calculates the absorption coefficients in terms of this decrease. Thus far there has been little theoretical justification of this method, although it has been experimentally checked with pressure vane measurements and by an unpublished method by Saxton. The methods of Hubbard[2] and Hershberger[3] are more rigorous but call for rather involved technique. The advantage of the Pielemeier method, if it can be justified, is that it enables one to measure velocity and absorption on the same experimental run, which is a very desirable arrangement.

It is proposed in this discussion to derive more rigorous relations for the variation of plate current with reflector positions and set up a method of measuring the absorption from plate current readings. It will be shown in the following that the Pielemeier method is a fair approximation when the reaction on the sound wave on the crystal is small.

INTERFEROMETER THEORY

It is assumed that, when an air column resonates with an oscillating crystal, it acts on the crystal in such a way that the change in the maximum strain of the crystal produced by moving the reflector from a position of resonance to one of anti-resonance is proportional to the change of pressure amplitude of the particles vibrating at the face of the crystal. The piezoelectric-motive force being proportional to the strain, we have

$$p_m \propto E_m, \tag{1}$$

where p_m is the pressure amplitude and E_m the maximum value of the alternating impressed e.m.f. The problem then resolves itself into two parts: (1) relating Δp_m with the absorption coefficient and the position of the reflector; and (2) obtaining a relation between ΔE_m and the change of plate current in an oscillator such as is drawn in Fig. 1.

An equation relating the pressure amplitude to reflector position was first derived by Hubbard[2] and Hershberger[3] independently. At a resonance position the pressure amplitude at the crystal is

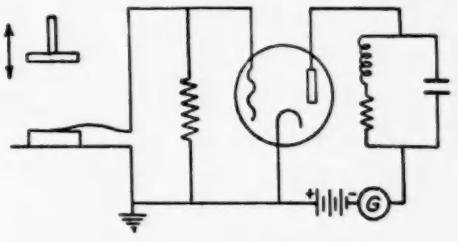


FIG. 1. Pierce oscillator circuit.

* This research was carried out at the Pennsylvania State College, State College, Pennsylvania.

[1] W. H. Pielemeier, Phys. Rev. **34**, 1184 (1929); **41**, 833 (1932).

[2] J. C. Hubbard, Phys. Rev. **38**, 1011 (1931); **41**, 523 (1932); **46**, 525 (1934).

[3] W. D. Hershberger, J. Acous. Soc. Am. **3**, 263 (1931); **4**, 273 (1933); Physics **2**, 269 (1932).

[4] H. O. Kneser, Ann. d. Physik **16**, 347 (1933).

[5] A. van Itterbeek and P. Mariens, Physica **4**, 207, 609 (1927).

given by

$$p_m = A\frac{\sinh(2\alpha r+\beta)}{\cosh(2\alpha r+\beta)-1}, \tag{2}$$

where A is a constant, α the amplitude absorption coefficient per unit length, r the distance between reflector and crystal, and β is approximately equal to $1-\gamma^2$, where γ is the absorption coefficient.[6] It should be pointed out that the factor γ is due to imperfect reflection at both crystal and reflector. Its value for some gases and some interferometers has been determined by Alleman,[6] who also derived an equation analogous to (2).

At a corresponding antiresonance position, (2) becomes

$$p_m' = A\frac{\sinh\left[2\alpha\left(r+\frac{\lambda}{4}\right)+\beta\right]}{\cosh\left[2\alpha\left(r+\frac{\lambda}{4}\right)+\beta\right]+1}. \tag{3}$$

Δp_m is the difference between (2) and (3). Some simplicity is gained by neglecting $\lambda/4$ in respect to r, in which case

$$\Delta p_m = \frac{2A}{\sinh\chi}, \tag{4}$$

where χ is equal to $(2\alpha r+\beta)$. If this approximation is not made, the more general expression is

$$\Delta p_m = \frac{2A}{\sinh\chi}\left[\frac{1\pm\frac{\alpha\lambda}{4}\tanh\frac{\chi}{2}}{1\pm\frac{\alpha\lambda}{2}\tanh\frac{\chi}{2}}\right]. \tag{4a}$$

The average of the $\pm$ values above is approximately

$$\langle\Delta p_m\rangle_{Av} \cong \frac{2A}{\sinh\chi}\left[1+\frac{\alpha^2\lambda^2}{8}\tanh^2\frac{\chi}{2}\right]. \tag{4b}$$

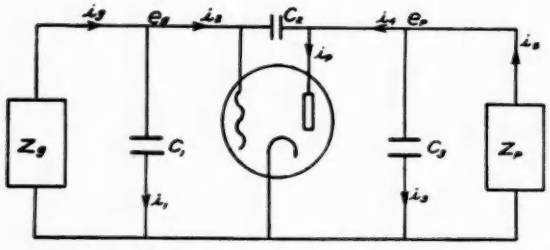


FIG. 2. Schematic drawing of Pierce oscillator circuit.

[6] R. S. Alleman, Phys. Rev. **55**, 87 (1939).

The second term in the bracket is negligible in ultrasonic work. For $\alpha\lambda$ as great as 0.2, it will have a maximum value of 0.005. A precise value of Δp_m will then be obtained from (4), if the average value of p_m' on each side of p_m is used.

OSCILLATOR THEORY

We set about to obtain a relation between ΔE_m and I_p, the latter being the plate current as read on a d.c. meter. Figure 2 is the equivalent circuit of the oscillator of Fig. 1. Here C_1, C_2, C_3 are the interelectrode capacities. Z_p is the impedance of the tuned plate circuit, Z_g the impedance of the crystal circuit. Following Wright[7] it is possible to obtain i_p in terms of e_g. The lower case symbols indicate instantaneous values of the plate current and the voltage impressed on the grid, that is, across the crystal.

Using Kirchhoff's laws and the fundamental equation of vacuum tube theory (assuming a linear characteristic for the tube),

$$i_p = \frac{-i_5 Z_p+\mu_a e_g}{r_p}, \tag{5}$$

we solve for i_p in terms of e_g, and obtain

$$i_p \cong \frac{\mu_a e_g}{r_p+j\left[2\omega\left(C_2+C_3+\frac{C_2}{\mu_a}\right)X_p^2-\frac{r_p\omega C_1 R_p}{\mu_a}\right]}, \tag{6}$$

in which $Z_p=R_p+jX_p$ has been substituted and several small negligible terms have been dropped.

Several things may be noticed from this relation: (1) The plate current slightly lags the impressed e.m.f., since the term in the bracket containing X_p is positive and the larger; (2) the dynamic characteristic curve has, as expected, a slope which is less steep than the static characteristic curve; (3) the plate current does not depend explicitly on any constants of the crystal circuit, but on the tube and plate circuit constants and the impressed e.m.f. from the oscillating crystal.

In general, it is necessary or desirable to use vacuum tubes with non-linear characteristics. In that case the resistance r_p is not a constant, but a variable which must be taken into account. A more general method of attack is available.

[7] J. W. Wright, Proc. I. R. E. **17**, 127 (1929).

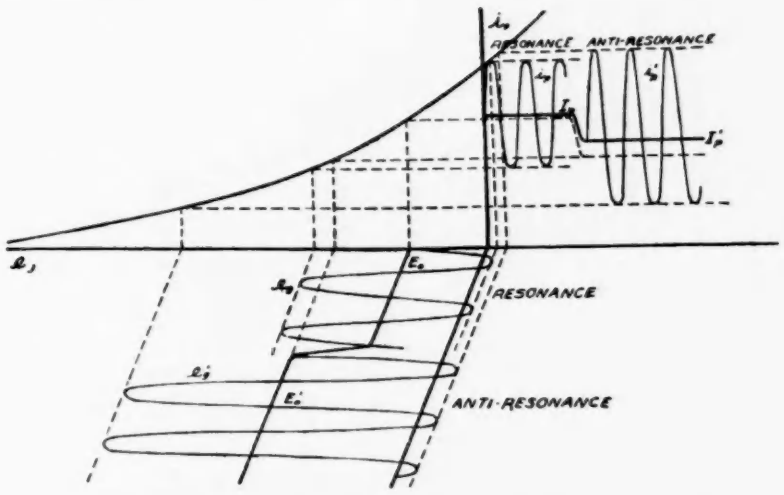


FIG. 3. Grid-voltage *vs.* plate-current characteristic curve showing effect on oscillator of changing from resonance to anti-resonance.

The plate current i_p is a function of the grid voltage e_g. e_g may be represented as

$$e_g = E_0 + E_m \cos \omega t, \tag{7}$$

where E_0 equals the grid voltage at the operating point on the characteristic curve. E_0, in turn, is a function of $E_m \cos \omega t$ when a grid leak is used, so that, in general, i_p is best represented by a function of the form

$$i_p = I_0 + c_1(E_m \cos \omega t) + c_2(E_m \cos \omega t)^2 + c_3(E_m \cos \omega t)^3 + \cdots. \tag{8}$$

The time average of this expression is the d.c. plate current, I_p. Only the even terms contribute to the integral, so that

$$I_p = I_0 + \tfrac{1}{2}c_2 E_m^2 + \tfrac{3}{8}c_4 E_m^4 + \cdots. \tag{9}$$

I_0 is the plate current when no alternating e.m.f. is impressed. The constants c_2 and c_4 are, in general, functions of the tube and plate circuit constants and of the grid leak resistance. All these factors are fixed after the circuit is tuned.

Consider now the effect of changing the length of the sound column which reacts on the amplitude of vibration of the crystal. An expression for the plate current at resonance and anti-resonance is desired. The effect of going from a position of resonance to anti-resonance is to change the pure resistance of the equivalent circuit of the crystal.[3] In order to sustain oscillations in the crystal, the plate circuit must feed just enough power back into the grid circuit to balance the losses there. When oscillations occur, a condition of "equilibrium" tends to be upset by changing the resistance of the crystal, that is, by moving the reflector. The amount of power fed back into the grid circuit is determined entirely by the constants of the tuned plate circuit which remain the same once the circuit is tuned, as we previously discussed. The only way the "equilibrium" can be restored is to change the operating point on the characteristic curve. This explanation accounts for the fact that the crystal will not remain oscillating (1) when operating on the linear part of the characteristic curve, or (2) when permanent c bias is used, *except when considerable grid current is drawn*, which is an objectional feature. The drawing of grid current tends to shift the operating point, that is change the plate resistance, until the condition of no power loss or gain in the grid circuit is maintained. It is very desirable in this work to use a large grid leak resistance for maintaining the grid bias. This has the added advantage of keeping the grid current very small.

The effect on the plate current of going from a position of resonance to anti-resonance is shown in Fig. 3. It is seen that the average plate current is higher at a position of resonance, although the amplitude is smaller. The shift in operating point is due to the slight increase of

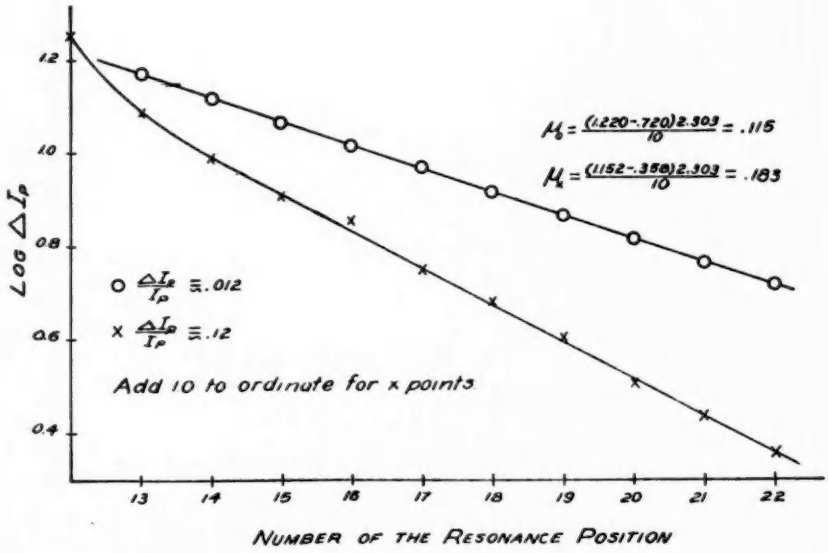


FIG. 4. Effect of large ΔI_p on slope of absorption curve.

grid current which tends to make the grid more negative. All the changes in voltage and current in this diagram are exaggerated, of course, to make the drawing clearer.

Let us assume that the plate current can be represented sufficiently by (7) in which all terms higher than the fourth have been dropped. Let ΔI_A be the difference between the plate current at resonance and anti-resonance at reflector position A, and ΔI_B the corresponding value at position B. Let ΔE_A, ΔE_B be the corresponding values of the change of E_m in going from resonance to anti-resonance. Then by subtraction,

$$I_A = \tfrac{1}{2}c_2\Delta(E_A^2) + \tfrac{3}{8}c_4\Delta(E_A^4); \qquad (10)$$

$$I_B = \tfrac{1}{2}c_2\Delta(E_B^2) + \tfrac{3}{8}c_4\Delta(E_B^4). \qquad (11)$$

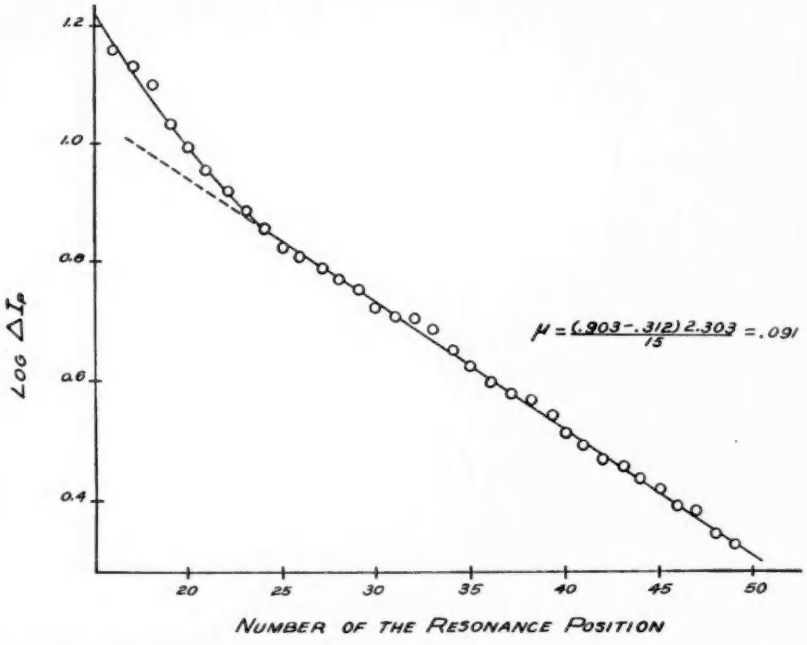


FIG. 5. Effect of distance of reflector on slope of absorption curve.

Considering only the cases when ΔE_A and ΔE_B are small, $(\Delta E_A/E_A=0.01)$, we may perform the differentiation without losing accuracy:

$$I_A=(c_2+\tfrac{3}{2}c_4E_A^2)E_A\Delta E_A; \tag{12}$$

$$I_B=(c_2+\tfrac{3}{2}c_4E_B^2)E_B\Delta E_B. \tag{13}$$

Now, we have approximately

$$\frac{E_A}{E_B}=\left(\frac{I_0-I_A}{I_0-I_B}\right)^{\frac{1}{2}}=\left(1-\frac{I_A-I_B}{I_0-I_B}\right)^{\frac{1}{2}}. \tag{14}$$

For a typical measurement, $I_A-I_B=0.1$ ma, $I_0=15$ ma, $I_B=10$ ma, so that

$$E_A/E_B=(1-0.1/5)^{\frac{1}{2}}=0.99,$$

or within the limits of precision of measurement, $E_A=E_B$. The use of the logarithm later decreases the error of this approximation by about half. From (1), (4), (12), (13), we have

$$\frac{I_A}{I_B}=\frac{\Delta E_A}{\Delta E_B}=\frac{\Delta P_A}{\Delta P_B}=\frac{\sinh(2\alpha r_B+\beta)}{\sinh(2\alpha r_A+\beta)}$$
$$\fallingdotseq\exp[2\alpha(r_B-r_A)], \tag{15}$$

the last step being true, if either the path length or the absorption coefficient is large, which can always be made the case by making the path length long enough. Notice that the troublesome reflection coefficient drops out under these conditions. We shall also substitute

$$\mu(n_B-n_A)=2\alpha(r_B-r_A), \tag{16}$$

where μ is the coefficient of *energy* absorption per wave-length and n_B-n_A is the number of *whole* wave-lengths between the points A and B. We thus obtain

$$\mu=\frac{2.303}{n_B-n_A}\log_{10}\frac{\Delta I_A}{\Delta I_B}, \tag{17}$$

which is the Pielemeier equation.

Values to about two percent are the most that can be expected for the absorption coefficients in most gases at high frequencies. These equations will give such precision, providing the measurements are exact enough and are made within the limits allowed by the approximations given above. The approximations may be summed up and hold when the experiments are carried out under the following conditions:

$$\frac{\Delta I_A}{I_B}<0.03; \tag{18}$$

$$\left.\begin{matrix}\mu n_B\\ 2\mu n_A\end{matrix}\right\}>2.5. \tag{19}$$

EXPERIMENTAL VERIFICATION

The effect of condition (18) is shown in Fig. 4 plotted from two runs made on CO_2. The graph of $\log \Delta I_p$ against the number of the resonance position is made. The points marked by (o) were made with small sound reaction on the crystal. The points marked (x) were made under the same conditions except that the oscillator was tuned so that the reaction of the sound column on the crystal changed the plate current about ten times as much in going from a resonance to an anti-resonance position. The slope of the second curve is much greater, giving (if the Pielemeier equation is improperly used) a value which is much too high for the absorption. This explains to some extent some of the discrepancy of the reported values in the literature.

The effect of condition (19) is shown in Fig. 5, also from a run made on CO_2. It is seen that after the 25th resonance position, the curve is a straight line. This is the point at which the ratio of hyperbolic sines approximates a pure exponential decrease. Use of the bent portion of the curve could be made if the reflection coefficient for the interferometer and the gas has been previously determined. However, this is not usually done.

CONCLUSION

A rigorous derivation of the Pielemeier equation has been made. The limits of precision of its use have been experimentally tested and agree with theory. This taken with the previous experimental justification of the method by Pielemeier and co-workers now seems to warrant its use for more extended investigations of the absorption of sound in gases.

Acknowledgment is made for aid furnished by many members of the Physics Department at The Pennsylvania State College while this work was being carried on.

Acoustic Laboratory in the New RCA Laboratories[1]

HARRY F. OLSON
RCA Laboratories, Princeton, New Jersey

(Received June 25, 1943)

Modern facilities for development and research in all branches of acoustics are provided in the new RCA Laboratories. The new Acoustic Laboratories include the following: a free-field sound room, a large sound stage, a standard living room, a soundproof room for life tests, dust-free rooms, magnetic laboratory, a live room, a field laboratory and towers, and conventional communication type laboratories. The free-field sound room is designed to provide acoustical conditions as obtained in free space outdoors under ideal and normal test conditions. The large sound stage is designed for tests of sound pick-up in standard conventional settings. By a change in "acoustics" the sound stage may be converted into a small theater for sound reproduction tests. The living room laboratory is designed to be the acoustical equal of the ideal living room in which sound reproducing instruments such as radios and phonographs may be developed and tested for normal home use. The soundproof room is provided with special walls and doors for testing loudspeakers at high levels without annoyance to adjoining rooms. The magnetic laboratory is equipped with apparatus for making magnetic measurements and several types of magnetizers for magnetizing permanent magnets. The dust-free rooms are used for assembling structures. The live room is designed for testing of sound-absorbing materials. The conventional laboratory bays include all types of measuring equipment: oscillators, amplifiers, recorders, bridges, etc. Multiple audiofrequency lines are provided so that laboratories may be interconnected. The remotely located field laboratory is used for conducting free-field response, power, and life tests.

INTRODUCTION

THE new RCA Laboratories at Princeton, New Jersey provide modern facilities for development and research in all branches of acoustics. The new Acoustic Laboratories include the following: a free-field sound room, a large sound stage, a standard living room, a soundproof room for life tests, dust-free rooms, a magnetic laboratory, a live room, a field laboratory and towers and conventional communication laboratories. It is the purpose of this paper to describe these elements of the new Acoustic Laboratory.

FREE FIELD SOUND LABORATORY

Acoustic measurements under free-field conditions are required in the development of the major portion of electro-acoustic transducers. The most obvious and direct solution would seem to be to make the measurements out of doors at a great distance from all reflecting surfaces. There are several objections to outdoor testing, as for example: interruptions due to wind, rain and snow; noise both natural and man made; difficulty in arranging experiments at sufficient distance from the earth so that reflections will be negligible. In view of the importance of free-field testing and the objections to outdoor arrangements, it is obvious that a free-field sound room is an almost indispensable part of the equipment of an acoustical laboratory. It is the purpose of this section to describe the free-field sound room in the RCA Laboratories.

The objective in the design of a free-field sound room is to reduce to a negligible amount all reflections from the boundary surfaces of the room. This is equivalent to a very small ratio of generally reflected to direct sound. The ratio[2] of the generally reflected to the direct sound in a room is:

$$E_R/E_D = 16\pi D^2(1-a)/aS \qquad (1)$$

where E_R = energy density of reflected sound,
E_D = energy density of the direct sound,
D = distance from the source to the observation point,
S = area of absorbing material
V = volume of room, and
a = absorption coefficient.

An examination of Eq. (1) shows that the ratio of reflected to direct sound may be reduced by

[1] Presented at the twenty-eighth meeting of the Acoustical Society of America held in New York City, May 14 and 15, 1943.

[2] H. F. Olson, *Elements of Acoustical Engineering* (D. Van Nostrand Company, New York, 1940), p. 305.

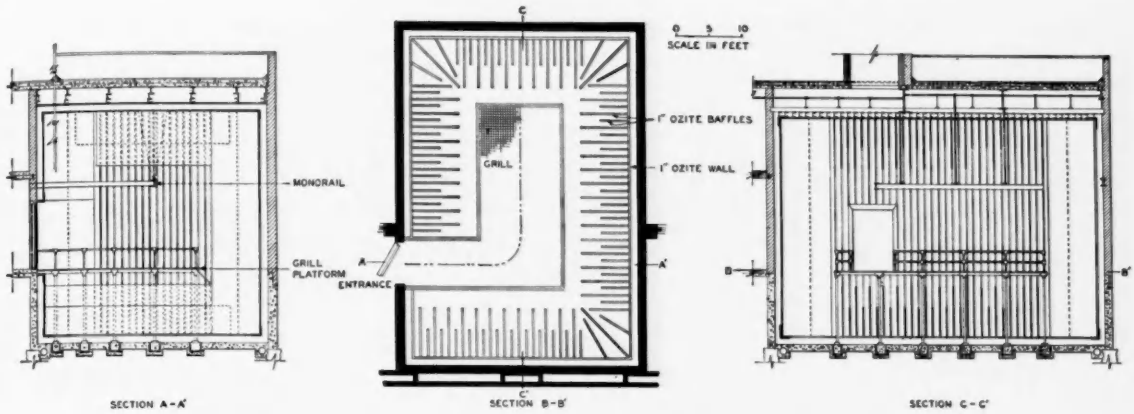


FIG. 1. End elevation, plan, and side elevation of the free-field sound room.

decreasing the distance between the source and observation point, by making the absorption coefficient of the walls near unity, or increasing the area of the walls. In other words, free-field conditions are approached by making the room large and absorption coefficient of the wall near unity. To satisfy the first requirement, the free-field room was made as large as seemed practical from an architectural and constructional standpoint. The dimensions of the free-field sound room, before acoustic treatment was applied, were as follows: 48 feet long, 36 feet wide, and 36 feet high. The next objective was to obtain an absorption coefficient as near unity as possible. The high and low frequency ranges present the greatest difficulty in attaining this objective. It is a comparatively simple matter to attain high absorption in the mid-frequency range.

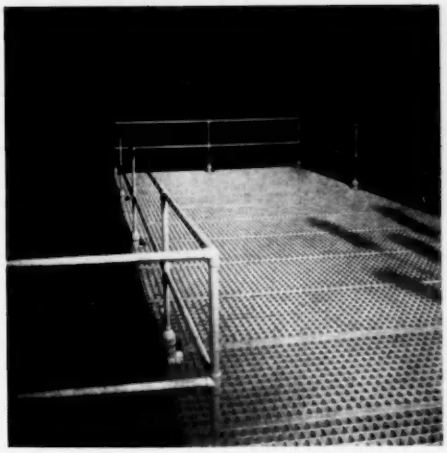


FIG. 2. Free-field sound room.

In the high frequency range the principal difficulty is reflection from grills, control boxes, and test apparatus. These reflections can be eliminated by acoustical treatment of these reflecting surfaces. In the case of the low frequency range it appears to be an inexorable fact that the ideal objective can only be attained in a relatively large room with correspondingly thick absorption material. An examination of existing rooms indicates that regardless of the form of treatment[3] it appears that absorption deviates quite rapidly from unity when the thickness of the treatment is less than a quarter-wave-length.

The absorbing system employed in this room is of the baffle type, that is, strips of absorbing material arranged normal to the walls of the room as shown in Fig. 1. Several years ago a smaller room (22 feet long, 20 feet wide, and 13 feet high) was treated with baffles. The performance of this room appeared to be comparable to rooms with equivalent thickness of other types of absorbing material. The advantage of the baffle type of treatment is the relative simple construction and lower cost as compared with more elaborate absorbing systems.

Plan and elevation views of the room are shown in Fig. 1. A photograph is shown in Fig. 2. One-inch Ozite is spaced one foot from the walls, ceiling and floor. One-inch Ozite baffles, seven feet in length and spaced two feet apart are

[3] In this statement, it is assumed that thickness of the material is measured to an outside boundary of relatively high acoustic impedance compared with the characteristic acoustic impedance of air. It is also assumed the treatment does not involve resonant systems.

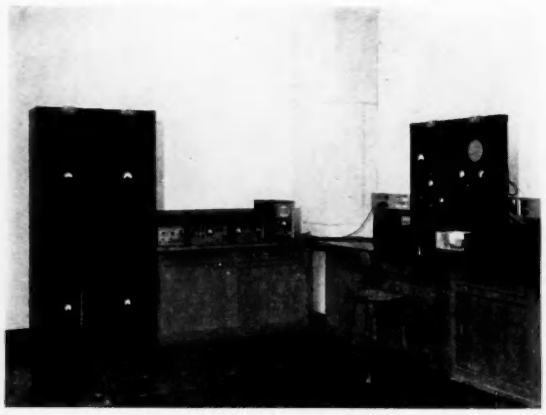


FIG. 3. Measuring equipment.

placed normal to the walls, ceiling, and floor. Four-foot baffles of the same material are placed between the seven-foot baffles. The total thickness of the absorbing material, measured from the outside wall, is eight feet. This leaves the inside dimensions of the room: 32 feet long, 20 feet wide, and 20 feet high. A special grill 12 feet wide and 24 feet long is supported on vibration-isolated feet. The ratio of open to total area in the grill is 0.87. This is a relatively open grill when it is considered that the grill platform will carry a load of 200 pounds per square foot. The floor level of the grill is located 11 feet above the floor level of the room. The floor level of the grill coincides with the first floor level which makes it readily accessible to the adjoining laboratory.

Measuring equipment used in conjunction with the free-field sound room is located in the adjoining laboratory. A photograph of a corner of this laboratory is shown in Fig. 3. The apparatus shown includes means for measuring the response frequency, power frequency, and directional characteristics of electro-acoustic transducers. Signal lines connect the free-field sound room with the adjacent laboratory, as well as all other rooms in the Acoustic Laboratory.

The acoustical merit of the room can be expressed by the deviation in sound pressure from an inverse distance characteristic. Pressure response frequency characteristics were obtained at various distances from a small loudspeaker. The maximum deviation in pressure from an inverse distance characteristic for various frequencies is shown in Fig. 4. It will be noted that the deviation in the mid-frequency ranges is negligible. The deviation at the high frequencies is due to the grill, overhead trolley track, power and signal outlet boxes. These units will be treated, which will make the deviations from an inverse characteristic practically the same as the mid-frequency range. The deviation at the low frequencies begins when the thickness of the material is approximately a quarter-wave-length. However, the deviation is only ± 1.7 db at 40 cycles at a distance of eight feet. At 40 cycles the thickness of the material is 0.28 of the wavelength.

The absorption coefficient of the walls may be determined from the ratio of direct to generally reflected sound. These two components may be determined by employing a velocity microphone. Two measurements are made—one with the normal to the plane of the ribbon passing through the source and the other with the plane of the ribbon passing through the source. The absorption coefficient-frequency characteristic of the walls of the room is shown in Fig. 5.

A low noise level is another essential requirement in a free-field sound room. The noise level in the free-field sound room, when the laboratories are in normal operation, is about 10 db. At night, when the shops are closed down, the noise level is 0 db. This shows that the sound treatment is also quite effective in absorbing sounds generated outside the room. The free-field sound room is heated by hot air forced through 48 openings in the floor. With the blower in operation the noise level in the room is about 20 db. However, it is not necessary to operate the heater during the day because the room is very well insulated thermally as well as acoustically. For example, if the heater is operated eight hours in every 24 hours, the temperature variation from 70°F is only ± 3°F on the coldest day.

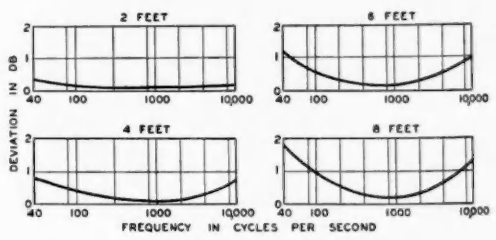


FIG. 4. Deviation of the pressure from an inverse distance characteristic for various distances from a sound source.

The above data and other measurements show that it is possible to make measurements in this room under essentially free-field conditions over the frequency range above 40 cycles for distances between the source and observation up to eight feet. This distance can be increased if either the source or the microphone, or both, are directional.

SOUND STAGE LABORATORY

Measurements made under free-field conditions determine the physical acoustic characteristics of the microphone or loudspeaker. In the collection of sound by microphones under normal operating conditions, there are many complex factors which influence the performance. The dispersion of sound by loudspeakers is equally complex. Therefore, after a microphone or loudspeaker with certain physical characteristics has been developed, the next step is a test under actual operating conditions. These tests require a sound stage with flexible acoustic characteristics. It is the purpose of this section to describe the sound stage in the RCA Laboratories.

A plan view of the sound stage is shown in Fig. 6. A photograph of one corner is shown in Fig. 7. The sound stage (48 feet long, 36 feet wide, and 24 feet high) is of adequate dimensions to permit practical working tests of microphones under a variety of environments. Two large monitoring rooms are provided on the sides of the sound stage. Large soundproof windows permit a good view of the entire stage from the monitoring room.

The walls and ceiling of the sound stage are finished in one-inch Absorbex, backed by four inches of rock wool blanket. The stage floor, for practical reasons, is covered with asphalt tile with practically no absorption. An abuse-resisting wainscoat extends up four feet from the floor.

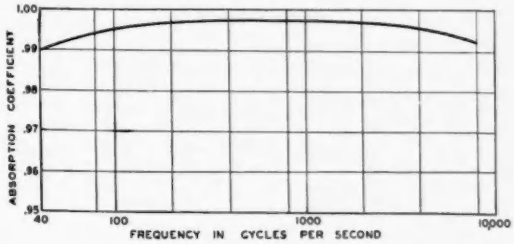


FIG. 5. Absorption coefficient-frequency characteristic of the treatment in the free-field sound room.

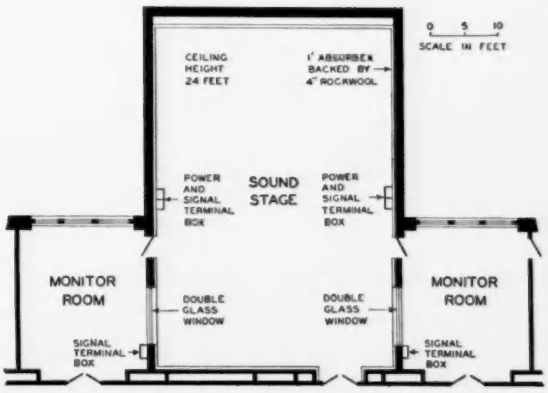


FIG. 6. Plan of the sound stage and monitoring rooms.

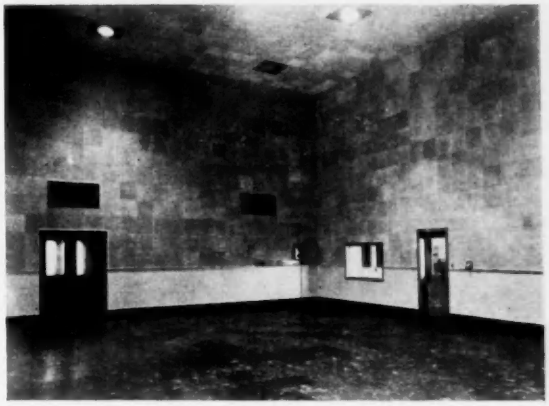


FIG. 7. Sound stage.

The measured reverberation time-frequency characteristic with no carpeting on the floor is shown in Fig. 8. The reverberation time is quite low and is about one-half that recommended for a normal broadcast studio of this volume (40,000 cubic feet). The reverberation time is made low so that flexible acoustic characteristics may be obtained. For example, in sound motion pictures and television the standard practice is to build sets upon a sound stage with very low reverberation time. Under these conditions, the acoustics of the collected sound is determined by the set. Added realism is attained by this expedient because the acoustics of the collected sound corresponds to the picture depicted on the screen. For tests under normal broadcast acoustic conditions, the reverberation time of the sound stage may be increased to optimum values by introducing reflecting surfaces on the walls. In this case "V'ed," polycylindrical or other dis-

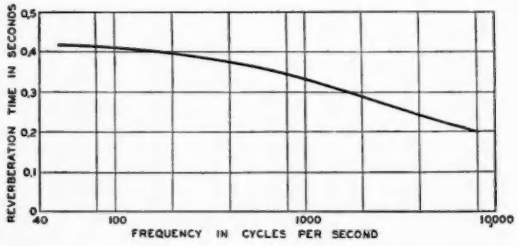


FIG. 8. Reverberation time-frequency characteristic of the sound stage.

persing surfaces may be used. This sound stage provides a means for testing the acoustical properties of these surfaces.

A low noise level is another essential requirement of a sound stage. The noise level in the sound stage when the laboratories are in normal operation is 20 db.

The sound stage is designed so that it may be employed as a small theater for the reproduction of sound. For these tests, the room may be "livened" by increasing the reverberation time. This can be accomplished by introducing reflecting surfaces along the sides and in the ceiling.

From the above description of the sound stage, it is quite evident that it is a flexible acoustic laboratory for testing microphones for sound broadcasting, sound motion pictures and television under typical operating conditions. In addition, it is designed so that it may also be used for testing large scale sound-reproducing systems under various environments.

LIVING ROOM LABORATORY

The radio receiver and phonograph constitute, by far, the largest number of complete sound-reproducing systems. Home sound reproduction is the principal application of phonograph and radio receivers. For this reason, the performance of a sound reproducer in a relatively small room is an extremely important problem.

The living room laboratory shown in the plan view of Fig. 9 is designed to be the acoustical equal of the average living room. The room is 24 feet long, 20 feet wide, and 8 feet 6 inches high. The room is finished with acoustical plaster backed by two inches of rock wool blanket. The reverberation time frequency characteristic is shown in Fig. 10. This reverberation characteristic approximates that of a typical living room in a home or apartment.

A photograph of the living room laboratory is shown in Fig. 11. Standard a.c. and d.c. power outlets are provided. Suitable antennas are brought to the living room over transmission lines. Audiofrequency signal lines are provided so that the living room may be connected to any part of the Acoustic Laboratory. These lines provide means for obtaining objective data, in the form of response frequency, nonlinear distortion, spatial distribution, intensity level, and transient characteristics, on sound reproducers operating in the room employing permanently installed measuring equipment in other parts of the Acoustic Laboratory.

The primary purpose of the living room is to provide a means for conducting subjective tests on complete reproducing systems under controlled conditions. This room provides a means of correlating subjective tests with objective tests outlined in the preceding paragraph.

DUST-FREE ROOMS

Dust-free rooms are provided for the assembly of the magnetic structures of microphones, loudspeakers, and other electro-acoustic transducers. The pressure in these rooms is kept above the

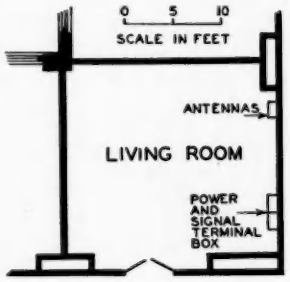


FIG. 9. Plan of the living room.

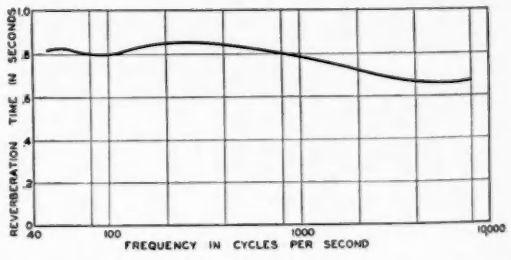


FIG. 10. Reverberation time-frequency characteristic of the living room.

ambient pressure of the adjoining room. The incoming air is filtered. In this way delicate mechanisms may be assembled without danger of contamination by dust particles.

LIVE ROOM

The absorption coefficient of an acoustic absorbing material may be obtained from reverberation measurements in a relatively live room. The live room for these tests is a room 24 feet long, 18 feet wide, and 13 feet high. The reverberation time characteristic of this room without any material is shown in Fig. 12. The reverberation time is about 4 seconds.

SOUNDPROOF ROOM

A soundproof room is used for testing loudspeakers at high levels without creating annoyance in adjoining rooms. A photograph of the soundproof room is shown in Fig. 13. The room is built with separate double masonry walls. Two heavy sealed doors lead to the chamber.

FIG. 11. Living room.

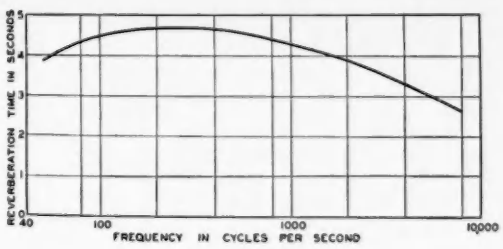


FIG. 12. Reverberation time-frequency characteristic of the live room.

FIG. 13. Soundproof room.

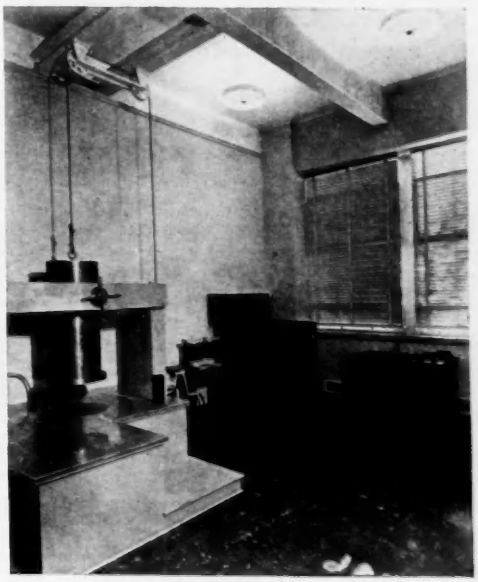


FIG. 14. Magnetic laboratory.

As much sound absorption as is practically possible is used to reduce the sound level in the room. A standard laboratory bench with a power outlet panel is installed in the room. Audio-frequency signal lines are provided so that the

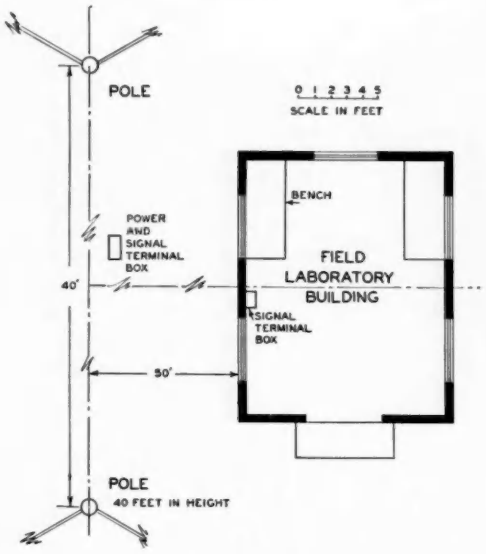


FIG. 15. Plan of field laboratory.

soundproof room may be connected to any other part of the Acoustic Laboratory.

MAGNETIC LABORATORY

The majority of electro-acoustic transducers employ magnetic systems. These include electromagnets, permanent magnets, transformers and field structures. A photograph of the magnetic laboratory is shown in Fig. 14. The specifications of the large pole type magnetizer are as follows: a magnetomotive force of 200,000 ampere turns. The pole pieces are 18 inches in diameter. The unit will carry 3,500,000 maxwells with negligible magnetomotive force loss in the magnetizer structure. The smaller pole type magnetizer is

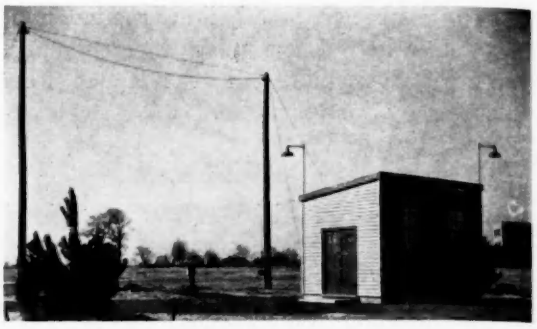


FIG. 16. Field laboratory.

suitable for small structures. An impulse magnetizer employing 3600 microfarads and an ignitron will deliver 2000 amperes. Apparatus is provided for the standard magnetic measurements.

ACOUSTICAL FIELD LABORATORY

The field laboratory is designed for outdoor testing of acoustical systems. A plan view of the field laboratory is shown in Fig. 15. The field laboratory is located on relatively open flat ground at a large distance from the main laboratory. A photograph of the exterior of the laboratory building is shown in Fig. 16. Two heavy poles are provided so that equipment up to 2000 pounds may be evaluated to a distance of 40 feet above the earth. Audiofrequency and power outlets at a point midway between the poles are connected to the field laboratory building. In this way standard response recording equipment may be set up permanently in the field laboratory and connected to the outside test locations.

The Extension of the Doppler Principle to Discontinuous Periodic Effects

LIONEL FLEISCHMANN
The Electric Auto-Lite Company Toledo, Ohio

(Received May 1, 1943)

THE Doppler effect has so far always been associated with wave motion which is a continuous periodic effect. In everyday life the note from a whistle or horn of a moving automobile or locomotive blown at the time of passing an observer is found to change rapidly from a higher pitch to a lower one.

An elementary graphical demonstration will show that discontinuous periodic effects, as for instance the time between hits of bullets fired by a machine gun on an airplane in motion, are subject to a similar law of change of frequency as effects due to wave motions.

We will assume that a source emitting such a discontinuous effect in a time interval of ΔT seconds is moving with a speed of v feet per second towards an observer who himself is moving in a straight line against the source with a speed of v_1 feet per second. Source and observer are originally distanced L feet apart. The effect or signal travels relative to space with a speed of c feet per second. The clock time of the source and of the observer is synchronized and is not influenced by motion, but as we want to establish the difference between the intervals of emission and reception we must distinguish between T the time of the source and T_1 the time of the observer.

In Fig. 1, the time T of the source and the time T_1 of the observer is represented on two lines at right angles to a line representing the distance L all drawn to proper scale, so that points on the straight lines OA, OC and O_1B represent, in a system of rectangular coordinates, the time and the distance traveled, respectively, by the source, the signal in space, and the observer. So in Fig. 1, $v\Delta T$ is the distance traveled by the source in the time ΔT while $v_1\Delta T_1$ is the distance traversed by the observer in the time ΔT_1. This stated, we shall now follow the performance of one complete cycle.

At the time $T=O$ the source at point O releases a signal whose time-distance relation is given by the straight line OC. The intersection of line OC with the line O_1B shows the position and the time when this signal is received by the observer who is moving towards the source. After an interval ΔT a second signal is released by the moving source which at this moment is a distance $v\Delta T$ from O. Again the signal travels with a speed c and, therefore, its time-distance relation is given by a line AD parallel to OC through the point P on line OA as the slope $T/(c\Delta T)$ $=$const. The intersection G of AD with O_1B marks the distance and time this second signal reaches the observer. It is now a matter of simple geometry to establish the numerical relationship between ΔT and ΔT_1. For this purpose Fig. 2 has been drawn which, as far as the left-hand side is concerned, is a repetition of Fig. 1.

As the lines OC and AD in Fig. 1 are parallel, it is easily seen that by drawing a line parallel to O_1B through P line PU in Fig. 2 is equal to GE in Fig. 1, likewise $PW=$ and $\|GE$ and $WU=$ and $\|FE$ and so $v_1\Delta T_1$, as well as ΔT_1, are reproduced in the positions shown by WU and WP in Fig. 2. From the triangle OXU we then get the relation

$$c(\Delta T-\Delta T_1)=v\Delta T+v_1\Delta T_1$$

and

$$\Delta T/\Delta T_1=(c+v_1)/(c-v).$$

In order to show the identity with the Doppler formula we introduce, instead of the time inter-

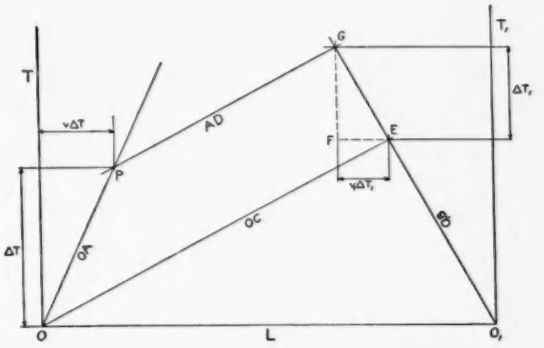


FIG. 1.

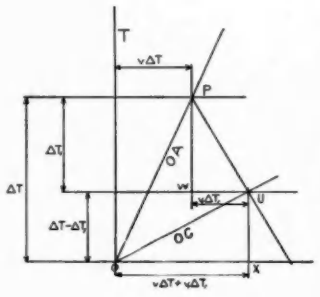


FIG. 2.

vals ΔT and ΔT_1, the frequencies $n=1/\Delta T$ and $n_1=1/\Delta T_1$. This furnishes $n_1=n(c+v_1)/(c-v)$, the Doppler formula for source and observer moving towards each other. It is easily seen how the figure must be modified when the sign of the velocities of source or of observer is changed.

In the derivation of the Doppler formula on the basis of wave motion it is generally contended that the source in motion with stationary observer and source stationary observer in motion represent two different physical conditions. In the geometrical method of approach no such difference need be assumed. The different numerical results namely $n_1=n(c)/(c-v)$ for source moving with speed v and observer stationary and $n_1=n(c+v)/(c)$ for source stationary and observer traveling with speed v are due to the fact that neither the speed of sound or light in space is altered by the speed of the source.

This difference does not exist when the speed of the source is added to or subtracted from the speed of the signal as in the case of a machine gun firing from an airplane in motion. If the muzzle velocity of the bullet with the gun stationary is m and the speed of the airplane is v then the bullet has a velocity of $m+v$ in regard to the surrounding space. Introducing this in the formula $n_1=n(c+v_1)/(c-v)$ furnishes $n_1=n(m+v+v_1)/m$. The n_1 refers to the frequency of bullet impacts under the assumption that the airplane and target are moving toward each other in a line joining both. Thus, after writing $n_1=n(m+v-v_1)/(m)$, we note that with either a stationary machine gun $v=0$ and the target moving with a speed $v_1=v$ or with target stationary and machine gun moving with a speed v we obtain the same impact frequency $n_1=n(m+v)/(m)$.

The graphical demonstration as outlined in Figs. 1 and 2 is also valid for wave motion. For, wherever the position of the time interval ΔT on the time line T, it will always produce the same reception interval ΔT_1 and, as we can consider the wave as composed of an infinite number of amplitudes varying as a sine function and each one repeating itself after the interval ΔT, each one of these will be received by an observer at

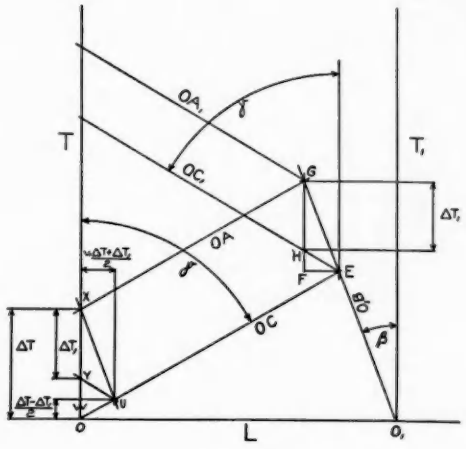


FIG. 3.

equal intervals of time ΔT_1 and so the wave reproduced with changed frequency.

This method is applicable also to such problems as, for instance, the frequency change brought about by a wall moving with constant speed toward a stationary source. The proof is given by Fig. 3 which combines in one the procedures of Figs. 1 and 2, and in which the straight line O_1B represents the time-distance relation of the wall moving with a speed of v_1. The signal, leaving the source at time O and having a velocity c, strikes the wall at a time and at a distance given by the intersection E of the straight lines OC and O_1B. From the wall this signal is reflected and starts back with the same speed c and its time-distance relation is now represented by the straight line OC_1 forming the same angle γ with a perpendicular as OC.

After a time interval ΔT a second signal leaves the stationary source; it meets the moving wall at a distance and a time given by the intersection G of the straight lines O_1B and OA. After reflection by the wall the straight line OA_1 represents the time-distance relationship for this sig-

nal and line GH represents the time interval of reception between signals for an observer stationed in front of the wall. To establish the numerical relation between ΔT and ΔT_1 we shift points G to X, H to Y, F to W and E to U. Then $XY=GH=\Delta T_1$ and angle $WXU=\beta$. Triangle OWU furnishes the relation $c(\Delta T-\Delta T_1)/2 = v_1(\Delta T+\Delta T_1)/2$ and $\Delta T/\Delta T_1=(c+v_1)/(c-v_1)$ or $n_1=n(c+v_1)/(c-v_1)$.

The graphical method can be further extended to the case where either the source or the observer is not moving on the line joining source and observer. Figure 4 shows the change of distance L with the source moving on the line AB with the constant speed V. In the time-distance graph, Fig. 5, the relation between distance and time is represented by an arc of a hyperbola, as for any distance L, as shown in Fig. 4, the following relation exists: $L^2=(AD-vT)^2+O_1D^2$ which is the equation of a hyperbola. A glance at the figure shows that the relation between ΔT and

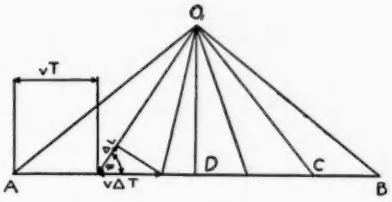


FIG. 4.

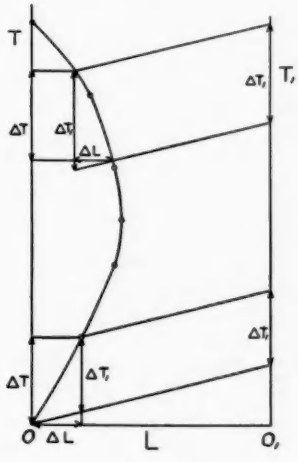


FIG. 5.

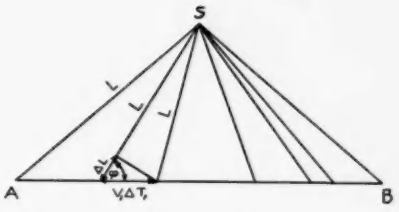


FIG. 6(a).

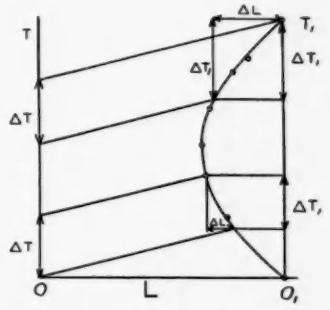


FIG. 6(b).

ΔT_1 is no longer constant. The ratio is smallest when the source starts from A going towards B. The ratio is one when the source is the shortest distance from O_1 and then goes on increasing as the source travels on. An approximate numerical expression can be obtained in referring to Figs. 4 and 5. As in first approximation $\Delta L=v\Delta T\cos\varphi$ and since $\Delta T=\Delta T_1+\Delta L/c$ one obtains $\Delta T_1 = \Delta T(1-v\cos\varphi/c)$ or $n_1=nc/(c-v\cos\varphi)$.

When the source is stationary and the observer moving with constant speed v, Fig. 6(b) shows the graph, and from this is obtained $n_1=n(c+v\cos\varphi)/c$.

A Discussion of Acoustic Cells for Airplane Engine Test Buildings

DARIEL FITZROY
Acoustic Division, J. L. Stuart Manufacturing Company, San Francisco, California
(Received May 29, 1943)

SOME months before Pearl Harbor the Acoustic Division of the J. L. Stuart Manufacturing Company became interested in the problem of sound attenuation in airplane engine test buildings. Since information on the subject was scarce, it was decided to make a series of thorough tests on existing installations in order to acquire a foundation upon which to consider future development.

Arrangements were made with the Army and Navy to make tests at various fields. Later the assistance of the National Gypsum Company increased the scope of the survey. All of the tests were made by the writer with the same set of instruments.

For the benefit of those who may not be familiar with these acoustic units, it might be explained that these buildings are equipped with a series of cells in which running tests of airplane motors are made.

It is necessary that these motors be subjected to a complete overhaul after a certain number of hours of operation. When they are reassembled they are put on test blocks and are "run-in" at varying speeds for periods ranging from 8 to 12 hours.

The noise thus generated, running almost constantly as it does, day and night, is considerable annoyance to the personnel at the airfield and even to residents living at some distance.

The quieting of this extremely intense noise presents a difficult problem. Since the motors are air cooled, it is necessary that an ample flow of cool air move in and out of the test chamber. Two acoustic cells are usually provided for each room. These cells are normally now in the form of a tunnel built at each end of the test chamber, one at the air intake and the other at the exhaust end. The tunnels are open at both ends, from the open air to the inside of the test chamber. Twenty-feet-square openings are common, with depths also of twenty feet.

Within these tunnels are placed a series of parallel ribbon walls approximately twelve inches apart. The walls are continuous, extending from the inside of the test room and from floor to ceiling. Sound absorbing materials are used for these ribbon walls. The majority of the installations use some form of porous cast stone as the acoustic absorber.

In considering the matter of tests, it became quickly obvious that relying upon the various airplane motors as the source of noise would not be suitable. This is, of course, because of the great variation in predominant frequency characteristics.

Therefore, it was decided to use an oscillator as the source of sound. In the tests, the oscillator was set successively at each of seven frequency bands. Readings were taken through the depth of the acoustic cell at 2′ 6″ increments in each of the bands. The bands selected, chiefly because some data we had acquired had been developed at these frequencies, were 50, 100, 200, 400, 800, 1600, and 3200 cycles.

In the earlier tests a source of warble note was not available. However, results which were considered satisfactory were obtained in these first tests, so no further effort was made to use warble notes in the subsequent ones.

The microphone was suspended from an endless pulley line running from the inside to the outside of the cell. It was located approximately in a central position as related to the absorbing material.

The test procedure was simply to start the oscillator in the selected frequency and to take successive readings at thirty-inch intervals, starting at the inside face of the cell.

The readings were taken in decibel increments. The results were constantly checked and in many cases the increment readings in individual frequency bands were taken several times.

The significance of the acoustical tests (Figs. 1–5) is difficult to appreciate without subjecting the results to a mathematical basis more readily inspected. Accordingly, Table I, based on the

tests, has been prepared to reveal the comparative effectivenesses of the various materials.

It is assumed that a composite noise has been created. This noise has been made up by seven individual noises of equal intensity, each from the various frequency bands. The actual intensity of the final composite noise is calculated to 60 decibels.

The mathematical relationship in the various increments and in the various materials is founded upon calculations proceeding from Figs. 1–5.

By inspecting the relative readings in Table I, the effectivenesses of the various types of acoustical cells may be compared at various depths.

Analyses of predominant frequency peaks showed the motor noises to have their major frequency peaks from 500 cycles downward. Usually definite peaks developed at around 120 to 250 cycles.

Therefore, an additional comparative chart (Table II), based on the attenuation developed in the tests, was prepared. This chart was calculated upon a composite noise of 60 decibels being created. Each of the four low frequency bands, 50, 100, 200, and 400 cycles, is taken in an equal intensity. This was to determine the relative effectivenesses of the various types of acoustical cell at the low frequency end.

The maximum over-all attenuation, in decibels, of the two composite noises, one of the seven frequency bands from 50 to 3200 cycles and the other of the four low frequency bands, 50 to 400 cycles, is shown for comparative purposes in the Table III.

Examination of the tables will reveal each cell to reach its maximum practical effective reduction, beyond which the reduction is relatively small, at varying depths. This, of course, depends

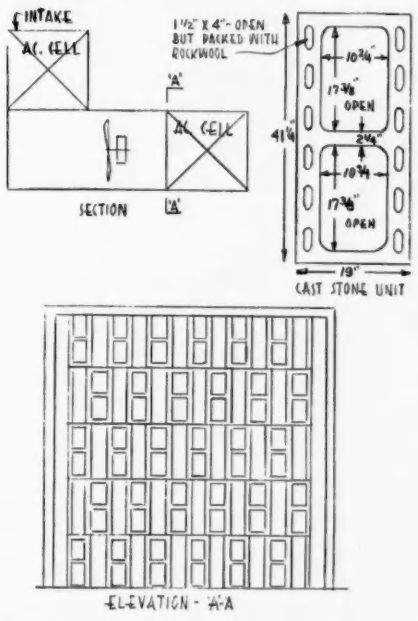


FIG. 1. Test with Cell I. Material: Cast stone blocks, 19″ wide×41¼″ high; cast with two openings, each 10¾″×17⅜″, and 6—4″×1½″ openings down each side of large open areas. All holes through entire block. Small holes packed with rock wool. Acoustical cell built up with these blocks on 30″ centers, in ashlar pattern. Block openings form continuous tube from inside to outside of cell.

Distance from inside face of cell (readings in decibels).

Freq.	0	2′6″	5′0″	7′6″	10′0″	12′6″	15′0″	17′6″	Total red.
50 c	66	63	62	60	58	54	53	51½	14½ db
100 c	64	59	55	54½	60	53½	53½	53½	10½ db
200 c	73	72	71	69	67½	66	63½	63½	9½ db
400 c	70	67	63	62	59	57	52	42	28 db
800 c	81	75	74	65	56	50	53	47	34 db
1600 c	80	82	75	69	51	55	54	46	34 db
3200 c	78	74	59	55	53	44	45	41	37 db

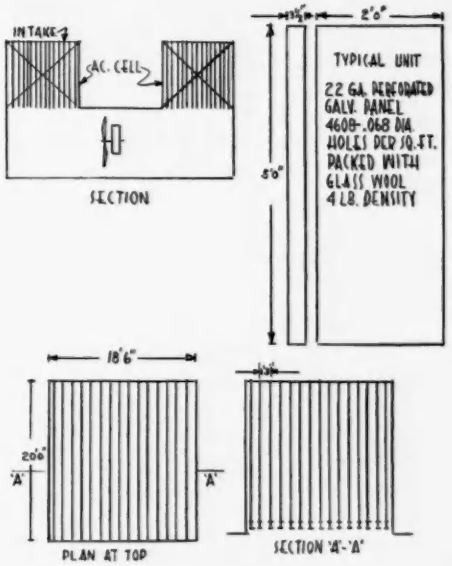


FIG. 2. Test with Cell II. Material: Perforated metal panels 3½″ thick, filled with glass wool; arranged in parallel ribbon walls on 15″ centers.

Distance from inside face of cell (readings in decibels).

Freq.	0	2′6″	5′0″	7′6″	10′0″	12′6″	15′0″	17′6″	Over-all
50 c	65	58	54½	47	41	41	35	36*	29 db
100 c	54	45	37	38	37	36	35	36*	18 db
200 c	68	64	59	51	47	47	47	47†	21 db
400 c	63	56	47	41	38	35	32	28	35 db
800 c	68	59	50	43	38	37	27	27	41 db
1600 c	73	65	59	55	47	43	35	33	40 db
3200 c	77	66	62	52	48	47	42	39	38 db

* Noise tractor passing.
† Flight pursuit ships taking off.

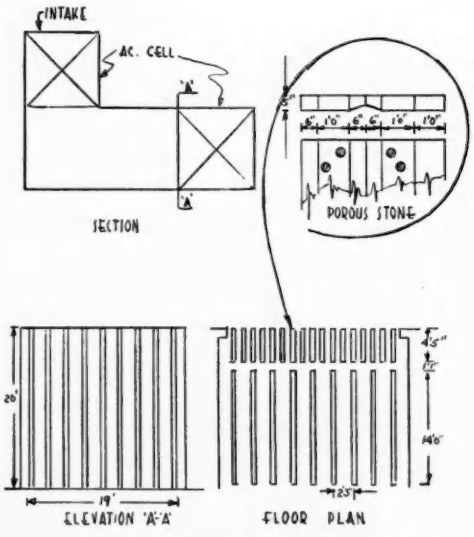


FIG. 3. Test with Cell III. Material: Cast porous stone —panels 5″ thick; 3″ holes cast through panels; holes staggered from top to bottom on 12″ wide panels; alternate solid and perforated panels every 12″. 31″ wall centers, in parallel, maintained for first 14′ 0″ from inside cell. Then 13″ vacant space after which walls are spaced on 15½″ centers, in parallel, for distance of 4′ 5″.

Distance from inside face of cell (readings in decibels).

Freq.	1′0″	2′6″	5′0″	7′6″	10′0″	12′6″	15′0″	17′6″	Over-all
50 c	60	60	59	56½	58	57	56	55	5 db
100 c	56	58	56½	55	49	54	49	54	2 db
200 c	64	61	57	53	55	55	58	55	9 db
400 c	65	63	63	57	60	63	57	56	9 db
800 c	67	56	65	57	54	53	45	43	24 db
1600 c	71	63	69	49	57	71	57	41	30 db
3200 c	73	68	67	63	60	54	53	47	26 db

upon the absorption efficiency in the various frequency bands.

It may be noted that there is very little additional reduction in any of the cells beyond the depths cited in Table IV.

At these depths the decibel reductions, according to the frequency bands selected, would calculate to be:

	Seven Bands 50–3200 Cycles	4 Low Bands 50–400 Cycles
Cell No. I	14.9	12.7
Cell No. II	22.5	17.7
Cell No. III	7.7	5.2
Cell No. IV	12.3	12.2
Cell No. V	10.5	12.1

It would seem safe to conclude that the Cell No. I type of construction should be 17′ 6″ or more in depth, since the low frequency bands would have their greatest practicable reduction at this depth. This would also hold true of Cells Nos. III, IV, and V.

On the other hand, the 10′ 0″ depth, or even the 7′ 6″ depth, is suitable with the Cell No. II

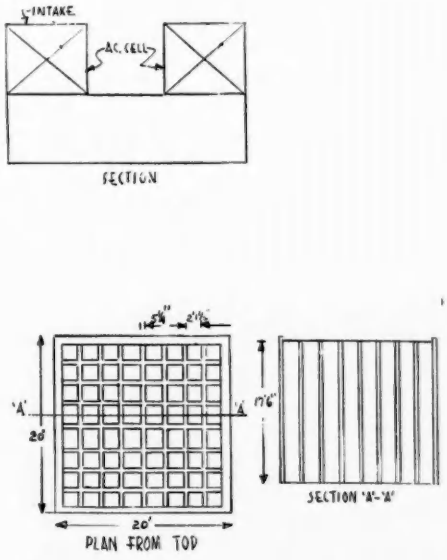


FIG. 4. Test with Cell IV. Material: Cast porous stone panels, 5¼″ thick; arranged in honey-comb squares 28″ on centers both directions. No rock wool inserts.

Distance from inside face of cell (readings in decibels).

Freq.	0	2′6″	5′0″	7′6″	10′0″	12′6″	15′0″	17′6″	Over-all reduction
50 c	57	55	53	54	51	50	49	50	7 db
100 c	57	50	50	49	47	46	41	39	18 db
200 c	64	63	62	59	58	57	57	56	8 db
400 c	68	62	53	53	51	50	48	48	20 db
800 c	70	68	65	59	51	51	49	48	19 db
1600 c	73	68	65	65	48	49	53	47	26 db
3200 c	71	67	63	53	49	46	49	47	24 db

type of construction. It might be noted that even at this shallow depth this cell supplies much more effective reduction than any of the others, even at the maximum attenuation depths for the others.

It seems conclusive to this writer, in view of his experience in these tests, supported by other results, that airplane engine test cell acoustical units need not be built more than 10′ 0″ deep, if the construction should be similar to Cell No. II. These tests and this analysis indicate clearly that Cell No. II is far more effective at ten feet than the others would be at 20 feet depth. And such was the case when 20-foot cells were tested. This belief is further supported in actual construction wherein this reasoning was utilized in the design of such a cell. Information in this connection will be seen further on in this article.

If the above statement is true, it becomes highly significant in view of construction costs.

Test cells are built in three types of design. In many of them both the exhaust and intake

stacks are vertical, being built on top of the test building in the form of a large chimney at either end of the test room. Others have vertical intake chimneys and horizontal exhaust tunnels. In this case one acoustical cell is built on top of the building and the other is constructed at one end of the test room.

The more recent buildings have been of the horizontal type, with both intake and exhaust tunnels on the same level as the test room.

The acoustic cells have varied in size in the past. At this time, however, most of them are in one of two sizes. One type has an over-all open area 14′ 0″ by 14′ 0″ with a depth of 18′ 0″–20′ 0″. The other has a 20′ 0″ by 20′ 0″ opening and a depth of 20′ 0″.

Taking the larger size, the significance of an ability to reduce the depth to 10 feet is obvious. Since the usual test building has the intake tunnels on one side and the exhaust tunnels on the other, with a test chamber of about forty-foot depth down the center, the elimination of the extra twenty feet of tunnel from the over-all dimension of the building would cut the construction costs of these buildings by approximately one-fourth. Savings with arrangements other than the horizontal type are obvious both as to construction costs and weights to be supported.

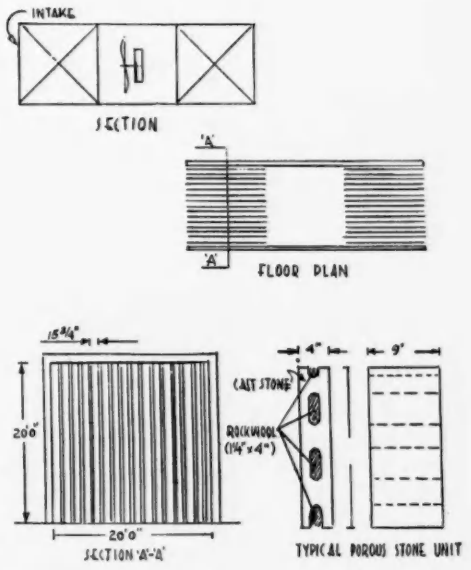


FIG. 5. Test with Cell V. Material: Hollow cast stone blocks, hollow areas within blocks packed with rock wool; blocks built into parallel ribbon walls 4″ thick; walls on 15¾″ centers.

Distance from inside face of cell (readings in decibels).

Freq.	0	2′6″	5′0″	7′6″	10′0″	12′6″	15′0″	17′6″	20′0″	Over-all reduction
50 c	57	53	51	50	49	48	45	46	46	11 db
100 c	53	52	49	46	45	42	41	39	38	15 db
200 c	59	50	49	53	54	55	53	50	47	12 db
400 c	68	67	64	57	50	45	45	40	46	22 db
800 c	69	63	60	56	43	41	51	44	38	31 db
1600 c	73	63	53	55	57	48	39	41	45	28 db
3200 c	73	61	61	53	49	48	43	41	43	30 db

THE USE OF THE REVERBERATION COEFFICIENTS

Probably one of the most difficult problems is in arriving at a relative evaluation of the various types of acoustic materials for this purpose. At the present time, the one type of acoustical information generally available is the reverberation coefficient. It was found advisable to discover, if possible, some foundation for utilizing these reverberation coefficients in judging the relative values of the various sound reducing materials.

TABLE I. Chart showing comparative reductions. (50, 100, 200, 400, 800, 1600, and 3200 cycles total 60-decibel intensity. Calculations based on test charts.)

Depth	Cell No. I	Cell No. II	Cell No. III	Cell No. IV	Cell No. V
0′–0″	60 db	60 db	60 db	60 db	60 db
2′–6″	57.6	52.7	57.8	56.6	55.5
5′–0″	53.8	46.9	57.8	54.3	52.8
7′–6″	50.5	41.1	53.8	52.7	50.7
10′–0″	50.4	37.5	53.0	49.6	49.8
12′–6″	46.9	36.6	56.2	48.6	49.5
15′–0″	45.1	35.3	51.7	47.7	49.2
17′–6″	44.6	35.6	52.3	47.5	45.6

Experiences in duct attenuation by many investigators have led to the conclusion that there is a definite relationship between the coefficients of absorption and the attenuation per foot. Much of this material has appeared in this journal. A list of such citations is extensive.

While considerably more tests are desirable to establish more accurate relationships, if such are possible, it may be stated here the present tests indicate two factors to be true:

(1) The attenuation is proportional to the ratio of the perimeter of the space between ribbon walls and the cross section of this space.

(2) The attenuation is proportional to the sound absorbing efficiency of the acoustic material.

Thus, stating the matter another way, the

TABLE II. Composite low frequency attenuation.

Depth	Cell No. I	Cell No. II	Cell No. III	Cell No. IV	Cell No. V
	Composite—50, 100, 200, 400—Reduced to 60 decibels				
0′–0″	60 db	60 db	60 db	60 db	60 db
2′–6″	57.4	53.6	58.3	56.7	57.2
5′–0″	55.3	48.1	56.4	55.0	54.5
7′–6″	53.1	42.3	55.7	54.0	52.6
10′–0″	53.1	39.4	54.8	52.0	52.1
12′–6″	50.0	38.7	56.7	51.0	52.0
15′–0″	48.3	37.4	54.0	50.0	51.5
17′–6″	47.3	38.0	54.8	47.8	47.9

factors seem to be depth, proportion of acoustic material to open space, and sound absorbing efficiency.

Some of the formulae on square duct attenuation are sufficiently close to meet most practical purposes.

Particularly, in a recent article[1] in this journal, Sabine set forth a duct attenuation formula which he states to have found sufficiently accurate for practical engineering work. Applying this formula, this writer may further state that the Sabine formula seems to be practical for reduction predictions for engine test building acoustical cells as well.

The Sabine formula is:

$$\text{Red. in db per ft.} = 12.6 \times (\bar{a})^{1.4} \times P/A$$

where $\bar{a}$ is the reverberation coefficient of the material, P is the perimeter of sound absorbing material in inches, and A is the area between walls in square inches.

Thirty tests were applied to this formula. The results at the 1600- and 3200-cycle bands were not satisfactory. But in all other frequency bands, with various materials, a high percentage of approximately accurate results were obtained.

Allowance had to be made for variations in coefficients of the materials. Generally, the cast stone blocks varied considerably in porosity, and, therefore, absorption, even in the same group.

The only material which could be certain to have approximately the same coefficients was the perforated metal with glass wool. This was because the perforations were mechanical and because the glass wool was packed to a uniform density.

It may be significant, in connection with the perforated metal and glass wool tests, that in the frequency spread from 100 to 1600 cycles ALL of the tests showed the formula to be correct or approximately so, when compared to the results obtained through the tests.

[1] Hale J. Sabine, J. Acous. Soc. Am. **12**, 56 (1940).

IMPORTANCE OF REVERBERATION CONTROL

One curious situation presents itself. In none of the buildings which the writer tested was there any reverberation control within the test chambers wherein the noises are originally created. It is evident from the highly reflective nature of the walls in these rooms that a considerable increase in intensity is built up before the sound ever starts through the acoustical cell. Calculations have shown this to be as much as seven or eight decibels.

It would seem that the first attack on the noise level should be here. Thus, if the noise level were prevented from being built up, it would not be necessary to provide that portion of the acoustic cell which later reduces it. It seems obvious that this construction economy could be achieved.

It may be that there is a belief that such porous materials might tend to collect dangerous gasoline vapor, with the attendant threat of explosion. But that reasoning would hold true also of the materials used in the acoustic cells. So it does not seem valid to this writer at this time.

In connection with this research work, tests were also made of the effectiveness of different arrangements of the materials. Readings were taken, using the identical materials to construct experimental cells at various spacings and in various arrangements. The tests were extensive and the data are too voluminous to include in this present discussion. It may be said there is ample indication that departure from the usual arrangement of parallel ribbon walls will result in definitely improved sound attenuation. Just

TABLE III. Maximum over-all attenuation at 17′ 6″ depth.

	Seven frequency bands (50–3200 cycles)	Four low frequency bands (50–400 cycles)
Cell I	15.4 decibels reduction	12.7 decibels reduction
Cell II	24.4 decibels reduction	22.0 decibels reduction
Cell III	7.7 decibels reduction	5.2 decibels reduction
Cell IV	12.5 decibels reduction	12.2 decibels reduction
Cell V	14.4 decibels reduction	12.1 decibels reduction

what amount of improvement may be made, or which of the alternative arrangements may prove most effective, this writer is unable to state at this time, as the experimental work and analysis have not been completed.

Within the past few months an opportunity was presented to this writer to put his conclusions to actual test in the design of an engine test building. It is regretted that under present circumstances he is unable to be specific as to the type of building and its location.

It was decided to utilize reverberation control in the test chamber in addition to the parallel ribbon walls in the baffle tunnels. Reverberation control was calculated to prevent an intensity rise of 6.7 decibels. The Sabine formula, applied to the specific material originally selected, predicted a reduction through the tunnel in its 10′ 8″ depth of 21.6 decibels. By adding the intensity reduction through reverberation control to the loss through the acoustic baffles a total reduction of 28.3 decibels seemed possible on a comparative basis with past installations inspected.

Circumstances arose which resulted in the use of a material with lower reverberation coefficients. To compensate for this, but without consulting this writer, the contractor cut down on the space between the ribbon walls.

At the new spacing, the originally planned material showed an attenuation possibility of 25.8 decibels through the acoustical cell itself, by formula. This added to the reduction through reverberation control, 6.7 decibels, predicted an over-all reduction of 32.5 decibels in the 10′ 8″ depth.

As has been stated before, the new material, however, had much lower absorption coefficients. Calculations showed the noise reduction through reverberation control in the test room would be approximately 5.7 decibels. This could not be verified. But since standard formulae were applied it may be assumed that the predicted reduction can be accepted as correct for practical purposes.

The Sabine formula predicted an attenuation through the acoustic tunnel of 15.4 decibels. Adding the reverberation control reduction of 5.7 decibels, showed an over-all reduction of 21.1 decibels to be expected.

After the completion of the acoustic tunnel, an oscillator test, similar to those previously made, was made. The results are shown in Fig. 6.

From the above the attenuation through the acoustic cell was calculated to be 15.9 decibels. This seems reasonably close to the formula prediction of 15.4 decibels.

A few minutes after the oscillator test was completed in this test chamber, the crew completed the assembly of a motor on the test block.

TABLE IV. Chart of most effective depths.

Cell No.	50 cycles	100 cycles	200 cycles	400 cycles	800 cycles	1600 cycles	3200 cycles	Composite 7-Band	Composite 4-Low Band
I	17′6″	12′6″	15′0″	17′6″	10′0″	10′0″	5′0″	15′0″	17′6″
II	10′0″	5′0″	7′6″	7′6″	7′6″	10′0″	7′6″	10′0″	10′0″
III	17′6″	10′0″	7′6″	17′6″	15′0″	7′6″	12′6″	17′6″	17′6″
IV	15′0″	17′6″	17′6″	15′0″	10′0″	10′0″	7′6″	15′0″	17′6″
V	15′0″	17′6″	5′0″	12′6″	10′0″	5′0″	7′6″	12′6″	17′6″

The motor was started and readings were taken. The reading inside the test chamber was 79 decibels. The reading, taken from a position just opposite, outside the acoustic cell was 63 decibels. The total actual reduction with the motor running was measured to be 16 decibels.

It might be noted here that this 16-decibel reduction at 10′ 8″ depth is greater than the reduction accomplished in any of the cells previously tested, with one exception, at 17′6″ depth. Compare, also, the over-all reduction, adding the reverberation control calculation, a total of approximately 21.7 decibels, with any of the over-all reductions in the previous tests, bearing in mind that the cell under present discussion is only about 60 percent as deep as those in the former tests.

Thus, the actual motor test seems to establish the validity of the oscillator test. And the results of both tests seem to verify the practical value of the Sabine formula application to motor test cell units.

There is yet another point that bears some discussion in connection with these cells. The acoustic engineer does not seem to have as yet the freedom of material selection he should have. Convention, or past procedure, seems to be a considerable obstacle.

It may be wondered why materials known to be more effective acoustically have not been

utilized more frequently for these baffles. As has been pointed out before, past procedure has influenced this. Also, many special considerations aside from acoustical effectiveness have intervened.

Just to cite one example: Severe and sometimes illogical climate resistance has been required. Since the acoustic cells are exposed to the weather, this is a consideration. Yet sometimes a decision has been made against the more effective material because of a belief that the less effective material will resist severe climate better. This writer has witnessed cases where the better acoustic material, even with strong recommendations to support its weathering ability, has been rejected because the final authority has intervened a personal, and no more reliably supported belief.

Satisfactory weather resistance is an economic factor. Yet it does not seem economic to insist upon the use of a material which will increase construction costs by 20 to 25 percent, because of the increased size of the cell necessary for the less effective material. This is particularly true where the over-all attenuation will be less, even in view of the increased cell size. Where the materials are approximately equivalent in weather resistance, even though each has special unique qualities, in this writer's opinion the difference in weathering does not warrant this added construction expense—particularly when it reacts also to the disadvantage of the primary purpose of the cell, its noise reducing effectiveness.

Also, in many cases the acoustic engineer, after designing effective units has been unable to enforce insistence upon the specific construction he has recommended. This is frequently brought about because the acoustic cells have been constructed, from specification, by general construction contractors who had no interest in the acoustic outcome. While living up to the letter of the specifications, the subtle distinctions which are so all-important to the trained engineer have been entirely ignored both by builder and inspector.

CONCLUSIONS

Summarizing the foregoing, the writer feels that certain accomplishments may be cited as

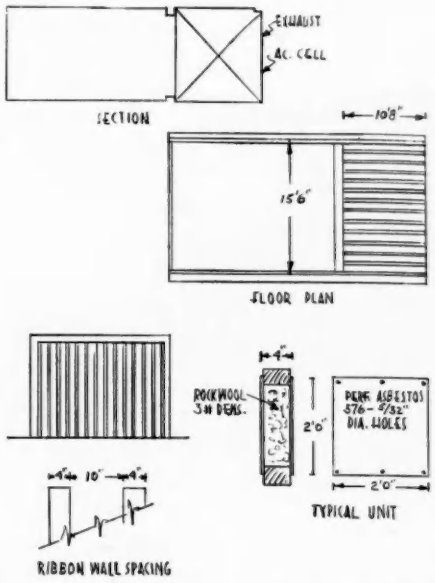


FIG. 6. Test with Cell VI. Material: Perforated asbestos and rock wool; parallel ribbon walls 4″ thick on 14″ centers.

Distance from inside face of cell (reading in decibels).

Freq.	0′0″	2′6″	5′0″	7′6″	10′8″	Over-all reduction
50 c	65	62½	61	57	56	9 db
100 c	72	64	59½	55½	51	21 db
200 c	75	69	60	61	57	18 db
400 c	85	67	60	54½	51	34 db
800 c	80	67	60	51	54	26 db
1600 c	80	77	69	66½	63	17 db
3200 c	86	73	70	67	64	22 db

the result of the tests, the subsequent analysis and this investigation:

(1) That the acoustical value of the materials used in engine test building noise reduction cells is almost directly as the reverberation coefficients, with particular emphasis upon the absorption in the low frequency bands.

(2) That these acoustical cells may be built at much shallower depths than has been the practice in the past, if more effective absorbing material is used.

(3) That material economies in construction costs may be effected.

(4) That the Hale J. Sabine duct formula is sufficiently accurate for application to engine test cell units for practical purposes within the critical frequency bands.

(5) That there is a practical attenuation limit in the reduction of airplane motor test noise, after which the reduction per foot is not economically practicable.

(6) That the critical frequencies applying to

engine test building noises lie between 50 and 500 cycles.

(7) That arrangement of the sound-absorbing materials differing from the usual accepted ribbon wall construction may result in greater acoustical efficiency.

(8) That reverberation control in the test chamber itself is a vital consideration that should be incorporated in these buildings.

(9) That the oscillator method of testing these cells is sufficiently accurate for practical purposes, and that this method has been found more satisfactory than the methods which have been utilized predominantly in the past.

(10) That an engineer may design acoustic cells for these buildings to definite noise reduction requirements. That he may calculate to within practical limits the amount of noise reduction to expect, if the materials can be held to reasonably uniform coefficients comparable to the samples tested for coefficients. That more efficient utilization of materials, space, and funds can result.

(11) That much more noise reduction can be supplied, at substantial savings in costs, if the designing acoustical engineer is allowed greater freedom in choice of sound-absorbing materials and their arrangement.

(12) That special requirements, many of which seem illogical and economically unsound, have been, and still are, handicapping the acoustical engineer in utilizing his training and knowledge to the best advantage.

Physics Building Fund

ACTING upon the recommendation of its War Policy Committee, the Governing Board of the American Institute of Physics on July 24 adopted a resolution authorizing the Institute to raise funds for the purchase of a suitable headquarters building—a "home office" in which the increasing activities of organized physics can be carried on and anticipated future developments effectively dealt with. In its recommendation to the Governing Board the War Policy Committee "foresees the necessity of extensive professional development in the field of physics and has urged the acquisition of a physics building to promote such development as well as to provide rent-free office space for the Institute and for other appropriate activities of physicists."

A highly suitable building located at 57 East 55 Street, New York was located and information about it, about the plan to raise funds for its purchase, and an outline of a broad plan of professional development for physics as proposed by the War Policy Committee was mailed to a large group of physicists and scientists in allied fields by a Building Fund Committee headed by Dean Homer L. Dodge.

The response to this request that physicists and their friends support the proposed plan of development and aid in its accomplishment, by purchasing for themselves and their organizations a headquarters building in keeping with the scope of the plan, has been amazingly good. On September 20, less than seven weeks after the first general announcement of the campaign, about $50,000 of the $75,000 asked for has been raised in the form of cash, war bonds, and other securities, and in pledges. This rapid and enthusiastic response permitted the Institute to exercise the short-term option it held on the 55 Street property and on September 22, the building became the property of the Institute.

Plans are not yet complete as to when the Institute's activities will be transferred to the new building but it will almost certainly be before the next meeting of the Acoustical Society in New York, at which time members of the Society will have an opportunity to inspect the new "home office" which they, together with other physicists of America, have purchased.

In the meantime there is the little matter of completing the Fund. Have you "purchased your share" in the building yet? Mail to the American Institute of Physics, 175 Fifth Avenue, New York 10, New York.

Sound-Proof Airplane Motor Test Chambers*

I. E. KATEL
Absorbit Inc., Bagnolet, France

(Received June 10, 1943)

THERE is no need of emphasizing before a technical society the seriousness of the noise generated by an airplane motor when it is on the testing bench and the necessity of insulating the surroundings from it. The noise presents, first, a real danger for the testing and operating crews, and, secondly, a great annoyance to those in the immediate neighborhood, in the office area of the factory, and to occupants of the surrounding congested urban areas, extending for blocks.

To provide protection for both of these groups we have resorted to the construction of sound-proof chambers around the test benches with openings for the intake and outflow of air. There are two ways in which such chambers can be constructed—in the shape of a U, i.e., with chimneys at either end of a horizontal chamber, or in the form of a long horizontal tunnel. The choice of the method of construction depends upon the nature and the extent of the available ground, the location of the factory in relation to the surrounding neighborhood and the cost estimate of the job.

While it is difficult to form a strict rule as to the advantages of one or the other type of construction, one can, in general, say that the U-type chamber requires less ground and is readily fitted into existing factories. The outgoing noise is directed upwards and so is less disturbing in the immediate surroundings (but will be more disturbing in remoter areas) than that emitted from the horizontal type. Further, the sound from the chimneys spreads out like that from the bells in the towers of a church, whereas from the tunnel type of chamber the noise, leaving the openings at or below the ground level, is in part attenuated by the ground and eventually by the neighboring trees and buildings. The construction of the horizontal chamber is simpler than that of the U-type, and the soft and porous sound-absorbing materials that must be provided in the intake and outflow channels are more protected against deterioration from the weather than in the case of the vertical chimneys. Finally, it is easier to introduce at some future time supplementary acoustic materials, or to make repairs, in the horizontal type, than in the U-type chamber.

Having been commissioned by the air ministry in France with the study of the problem of the reduction of noise in these chambers, the author has had occasion to plan both of these types of construction.

Considering that a single covering of absorbent material, except in excessive quantities, would not be enough to attenuate the noise sufficiently either for the control cabins or for the other buildings around the chambers, special sound-proof panels were applied between the concrete wall bearing the absorbent covering and the brick wall, and between two layers of concrete in the ceiling.

The construction of the horizontal type of chamber is shown schematically in Fig. 1.

The absorbing covering, composed of a porous material but rigid enough to withstand the strong air currents which are produced when propellers are in operation, is fixed to the walls and ceiling of the central part and the walls of the two tunnels. The air intake into the left tunnel is on a slope of solid concrete provided with undulations, to avoid the abrupt entry of

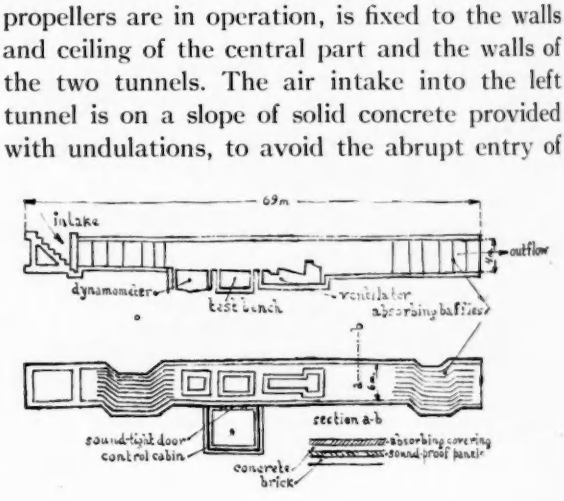


FIG. 1.

* Paper presented at the twenty-eighth meeting of the Acoustical Society of America, May 14–15, 1943, New York, New York.

air into the tunnel, and also to diminish the noise, to a certain extent, by dissipation at the surface of the slope. At the bottom of the slope, along its whole width, a channel is provided to collect rain-water.

It was not thought necessary to provide a similar slope on the other end of the outflow tunnel because the noise should here be damped sufficiently by the absorbing lining and baffles. These baffles are composed of panels of mineral wool covered on both sides with porous material, all held in place in a zinc framework.

In order to protect the panels on the side of the motor from oil spray they were covered for a certain distance with perforated zinc. The same precaution was taken in regard to the absorbing covering in the central part of the chamber.

The outlet tunnel is protected at its end with a metal curtain that can be closed at the end of the tests.

The control cabin is insulated to protect it against the entry of noise from other sources rather than from the noise of the test chamber with which it is associated.

The supports for the dynamometer, the test bench, and the ventilator are insulated against vibration.

For another factory, where the structure had to be put along the edge of a river, the U-type chamber was chosen. In this construction an effort was made to avoid the disadvantages of this type of construction without sacrificing insulation against noise. For this purpose the following modifications were made as seen in Fig. 2.

The intake and outflow of the air were made not vertical but lateral by gently curving the tops of the chimneys. In order that air currents in opposite directions might not set up turbulences, the chimney for the air intake was made lower than that of the outflow. Because of the limited length of the chamber and its relatively small volume, the attenuation of the noise was obtained in a satisfactory degree by sound-absorbing baffles fixed on a metal framework at the end of each of the chimneys, by absorbing

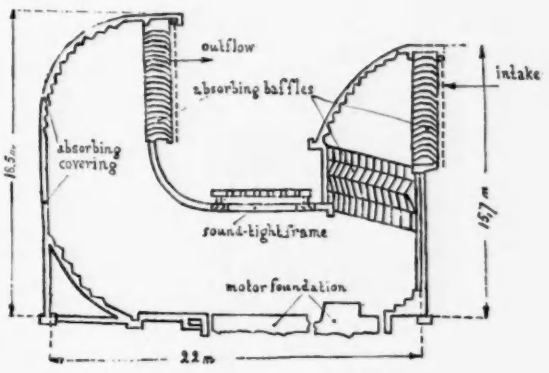


FIG. 2.

materials mounted stepwise on the vaulted surfaces at the top and at the bottom of the chimneys, by the absorbing coating on the walls and ceiling of the central portion and on the walls of the chimneys, and, finally, by a series of absorbing baffles placed vertically in the intake chimney in a slightly broken line and fixed to the structure by a metal framework.

For the reason given in the description of the horizontal chambers, it was not thought necessary to provide similar baffles in the outflow chimney. The penthouse over each chimney protects the first range of the absorbing baffles against rain.

Metal curtains under this penthouse provide closure of the chimney openings after the motors are stopped.

To provide daylight at the testing bench, the ceiling is provided with a skylight of transparent brick mounted upon a sound-tight frame.

The sound-absorbing material in the neighborhood of the motor is protected against oil spray, as in the horizontal chamber.

The ducts for pipes and cables leading from the chamber to the control cabin and to the outside are provided with sound-proof traps.

With this construction, the two typical disadvantages of the U-type structure are avoided; the entry of rain into the chimneys and the propagation of noise out to a large periphery, while sufficient attenuation of noise for the immediate neighborhood is retained.

Industrial Music and Morale*

DAN D. HALPIN
RCA Victor Division, Radio Corporation of America, Camden, New Jersey
(Received June 8, 1943)

THE rapidly increasing applications of industrial music and sound during the present decade have evolved from the resourcefulness of alert plant management, with labor. Research here and abroad indicates that music acts as a mental tonic, relieves fatigue and boredom arising from monotonous, repetitive type operations, and gives a "lift" to the tired worker. Its use in industry contributes to harmony of the work effort, improves health by lessening nervous strain, and promotes greater safety consciousness while logically reducing waste motion. In respect to production, music should not be considered as a panacea for industrial ills or as a means of increasing the rate of working during a program period. Instead, it should be considered a form of auditory stimulus which may so improve the morale of the workers that productive efficiency, measured in terms of output, may be materially improved during the entire work period.

Music-while-you-work is one phase of a plant broadcasting activity. Also, music for non-working times is of considerable importance.

A centralized plant broadcasting combination studio and control room, or dual layout with control room and adjoining studio, facilitates the distribution of speech and music throughout industrial areas. Because of its nominal cost, plus the important factor of a wide variety of artists, name bands, and orchestras which it provides, 78 r.p.m. standard recorded music is most generally used by industry.

Orthacoustic $33\frac{1}{3}$ r.p.m. recordings are also being used.

Before any music is used, however, a careful study should be made of its application to particular industrial operations. Much harm can result to the new industrial user from a lack of knowledge and understanding of certain fundamental principles. We trust that the following summary of our findings and suggestions, based on our own experiences, plus valuable information from England, will be of some assistance to those seeking information or advice.

PROGRAM TECHNIQUE

While diversified types of work logically may seem less fatiguing than monotonous operations, yet ennui arising from the pace of the current industrial effort often leads to reduced efficiency at the most important hour during busy work days. This period of the day might be aptly termed the "fatigue period," or the period when workers often are penalized because of abnormal rejects, and other workers may appear weary or listless. Waste motion increases, nervousness of new employees occasionally results in emotional outbursts, and "green" workers are often most susceptible to accidents. This factor of fatigue seems most apparent at about an hour and a quarter before mealtime, and also at the end of each shift. It is logical, therefore, that music introduced into work periods at these times may bring its greatest benefits and values to both employee and employer. Twenty-four minutes of popular tunes, familiar melodies, Strauss waltzes, some Hawaiian and western music, etc., called work music, coded "*F*" (for fatigue), are recommended for this period.

A second use of music for the work day is in helping to get everyone off to a good start at the opening of each shift. It also serves to remind each person of his patriotic obligations as a soldier of the production army. Selections suggested for this purpose are called opening or "*O*" music.

In the RCA Victor plants the "Star Spangled Banner" is heard daily at the start of each shift, with employees at attention in almost ritual-like fashion. In cases where reaction was tested by temporarily omitting this feature, a deluge of phone calls to the plant broadcasting studio resulted in a prompt reinstatement of this service —because employees wanted it. This precedes

* As presented at Acoustical Society of America Symposium on Music in Industry, New York City, May 14, 1943.

the opening program of marches, patriotic airs, lively selections, such as polkas, etc. For meal periods, programs have been specifically designed to build a listening audience receptive to other local plant messages and news, following the "Esso Reporter" type of brief, condensed newscast.

Music for mealtime is called luncheon, or "*L*" music. It features "request selections" of employees, salon and other restful music, comedy and novelty type recordings, etc. A fourth type of industrial music is designated as "*S*" or special occasion music, consisting of "Happy Birthday to You," the "Star Spangled Banner," a company's own recorded theme song, the "Wedding March," etc. Some executives suggested soft pedaling the latter selection because they did not want to put the idea of weddings into the minds of their female workers. A well-known manufacturer of precision electrical instruments says, on the other hand, that it is a splendid tonic with which to congratulate a newly-wed when she comes back to work on a blue Monday after being married over the week-end, only to have her new husband leave for points unknown that day. Some plants use brief programs of religious music at 11 A.M. on Sundays. One plant provided a Good Friday mealtime program including Gounod's "Ave Maria," sung by Schumann. Music programs for that afternoon were omitted, in view of the solemnity of the occasion.

The use of industrial music is a most important step for any industrial organization. A system must be thoroughly engineered, and programming intelligently handled, to obtain the fullest benefits and values inherent in such a system. It amounts to having your own "radio station" within the four walls of your plant. How well it is engineered to serve your specific needs, and how it is used, determines to a great extent the degree of return on this investment.

CENTRAL STUDIO CONTROL

For effective operation, a combination studio and control room, or separate studio and control room, for a plant is not only most logical, but very essential. Telephone operators should not be expected to handle a switchboard, locate key personnel, and operate music programming at the same time. Dual speed equipment—78- and $33\frac{1}{3}$-r.p.m. turntables, when available, are very important. A portable recorder is also very handy for interviews with those using the product you manufacture, at proving grounds, at camps with former employees now in the service, for recording and rebroadcast of news programs, messages to second- and third-shift workers, etc. The broadcasting of music should be considered in relation to its application over outdoor as well as indoor areas, offices, and laboratories. Volume at all times must be moderate, and carefully regulated manually, using a volume indicator in radio studio fashion.

Programming and operation of the system should be under the company official in charge of personnel. A director of broadcasting should report generally to the plant personnel director.

PROGRAM ESSENTIALS

For programming, the following essential points must be considered:

Familiarity

Tunes known by the workers are preferred.

Melody

The melody should be clear and well defined. The workers want to hear the tune, which must over-ride existing plant noise levels of anywhere between 65 to 102 db. Music that becomes involved or rhapsodical has a tendency to sound blurred and meaningless when broadcast in a factory, except at more quiet, non-work meal periods. Great care should be used in testing equipment. The same tunes should not be used too often. Volume should be of background type.

Constant Tone Level

The tone level or volume of a record in a program should be kept reasonably constant by monitoring each selection. Extreme disparity in volume becomes exaggerated in a factory and must be carefully controlled. By the programs of a plant broadcasting system, an audience is cultivated, built, and maintained.

Rhythm

Rhythm and tempo must be considered as a means of creating a spirit of cheerfulness and brightness that can be of benefit to operators engaged in most industrial operations. Hit parade tunes by name bands, because of their color, are particularly well received. Extremes of tempo should be avoided.

The theory that faster rhythm may speed the work process appears to be unsound—and rightly so. The work is not necessarily matched to the rhythm, but guided by it in many cases. Operations in plant areas vary so radically that attempts to match the rhythm to the work have rarely been practical.

Vocal Items

Much has been said, pro and con, on this debatable subject, but proof is lacking as to virtues or negative values for all operations. Experience dictates, however, that vocals, other than extreme vocals, are acceptable and practical under ordinary circumstances in many instances.

A governmental survey on industrial music recently completed discusses the above. Opinion is 50 percent for, and 50 percent against, vocals, depending on the person or company interviewed. (Copies of this report are available from the War Production Board (War Production Drive Headquarters), Municipal Center Building, Washington, D. C.

Organ Music

Organ music, properly controlled, has generally been very popular. Opinions as to this vary somewhat in relation to noise levels, type of personnel, equipment provided, etc. The wide dynamic range of the organ may result in frequent variations in tone level, requiring alert monitoring. Care must be taken to avoid "blasting" or "over-boominess" of the organ. Many recordings made of organ music have reasonably adequate compression, rendering them suitable for industrial use.

"Hot" Music

"Hot" music should be used "on request" only, and during mealtimes. Unusual or extreme solo instrumentalization should be confined to the same period.

DEDICATION OF A PLANT BROADCASTING SYSTEM

In addition to the problem of programming, the dedication and initial use of a plant broadcasting system may have considerable effect on its future usefulness to the industrial organization. Therefore, you may be particularly interested in the following suggestions.

Experience indicates that a plant broadcasting system should be dedicated as a service to employees for their benefit, and for increased productive efficiency—which should eventually mean continued work for capable workers. The idea of speeding production should never be mentioned. The word "morale" should not be overworked.

A practical eleven-minute program dedicating the system might consist of—

1. Recording "Stars and Stripes Forever," played while the group is gathering (three min.).
2. A greeting by the president or general manager (one min.).
3. An address by the chairman of the war production drive committee on this new facility for greater coordination, teamwork and employee benefit (two min.).
4. A message by an Army, Navy, Air Corps, or other service representative on communication in the war effort, as well as in production, citing the dependence of men of the fighting forces on the soldiers of production (two min.).
5. Invocation by a local clergyman (one min.).
6. Group singing of the "Star Spangled Banner," played by a recording over the plant system or by the plant band (two min.) (Victor record No. 27850).

(Total time of ceremony—11 minutes)

The plant union representative should be on the platform with other guests. Photographs of the dedication ceremony should be displayed on company bulletin boards and reproduced in the company house organ.

As in radio, music might be called the "sizzle that sells the steak"—paving the way for other

material used as a part of industrial music and sound program technique.

In addition to broadcasting of music, a plant sound system provides many other services. In addition to those listed below, the sound system may be used to locate executives and key personnel immediately, broadcast radio news, emergency instructions, time signals, and air raid warnings.

Morale Building Programs

1. War front to plant by letters or U.S.O. recordings from your men in the service
2. Recordings on performance of your product in combat, at camp, or proving ground
3. Heroes in person
4. Employees having relatives and former co-workers in the services
5. Army, Navy, Air Corps and WPB officials on citations
6. The President of the United States, the governor or civic officials
7. Treasury officials on war bonds
8. The president of your company, or his spokesman
9. War production drive committee
10. Award winners
11. Production drive rallies
12. Rumor clinic

To Stimulate Interest in

13. Red Cross blood donors
14. Community chest
15. Suggestion campaigns
16. Punctuality drives
17. Safety programs
18. Conservation
19. Salvage
20. Company achievements
21. Dramatic applications of company products

Company Information on

22. Promotions in personnel
23. Time schedules
24. Product
25. Regulations
26. New developments
27. Timely plant news
28. Consumer product reaction
29. Company history and progress
30. Employee sales
31. Departmental problems

Employee Benefits Such As

32. Group insurance
33. Income tax information
34. Mutual benefit association
35. Social security
36. Employment opportunities
37. Training groups
38. Conference sessions
39. Health-first aid courses
40. Nutrition
41. Transportation
42. Athletic and social events
43. Cafeteria and outdoor mealtime dance music
44. Educational opportunities

RADIO NEWSCASTS

Soldiers of production particularly enjoy hearing news at mealtime. News from the fighting fronts is welcomed by those within the "four walls" of a factory. Newscasts must be brief (about five minutes). The "Esso Reporter" newscast is an example of excellent condensed radio reporting. When meal periods are staggered, a recording of the best news program can be made and re-broadcast to other plant personnel.

Local plant news, bulletins, messages, etc., can follow the regular newscasts. Workers welcome information, but naturally resent attempts to educate them, according to British experience.

SUGGESTIONS

With a well-organized plant broadcasting schedule the "suggestion campaign" merits allocation of the best available program time. A comparison of results in our efforts to encourage suggestions, as a part of our "beat the promise" campaign, before Pearl Harbor, and after this event, indicates how effective plant broadcasting has been since 1941. Without using sound to encourage suggestions, in 1940, we had a total of 11,300 suggestions. In 1941, when a special portable sound unit was brought to each manufacturing department to dramatize this activity, in addition to mention of it over our then localized systems, we obtained 26,000 suggestions at our Camden plant, where the use of sound was featured, and 11,740 suggestions from our other plants. Of these suggestions, 90 percent were deemed worthy of investigation, and 18 percent adopted. In 1942 we decided to stress quality of suggestions rather than volume, and received a total of 36,420 suggestions, of which 94 percent were investigated and 34 percent adopted. Joe Bass, our Suggestion Supervisor, says the use of sound accounts to a large degree for the success

of our suggestion campaigns. (Recording of spot teaser on Suggestion Campaign demonstrated.)

TALKS BY HEROES

Brief addresses by war heroes have been found to be effective for improving employee morale. Those talks should be brief—not over three minutes indoors or over five minutes at an outdoor rally. (A complete program for a mealtime outdoor rally, industrial sing or Army-Navy "E" dedication generally should not exceed twenty minutes.) A most effective idea consists of presenting, from the plant studio, a former employee now in the service, for a two- or three-minute heart-to-heart talk with his former associates and friends. This procedure has been effective in reducing waste motion. Often a service man may feel obligated, otherwise, to visit each department in order not to slight any of his friends and admirers.

(Female voices have not proven as effective as male voices over a plant system according to qualified psychological experts.)

PAGING OR OBTAINING INFORMATION OVER A PLANT MUSIC-SOUND SYSTEM

When a paging call is made for a supervisory executive, the purpose is generally to obtain information, request his presence at a meeting, or for a long distance telephone call.

A practical paging method is for the central (phone) operator or studio broadcaster to say "Mr. Jones,—Mr. R. A. Jones, call 486." If attendance of the person is required at a meeting, in the office of the General Manager, for example, a code may be used, as follows:

"Mr. Jones,—Mr. R. A. Jones, call 0486." The zero preceding the phone exchange number indicates that R. A. Jones is expected immediately at an important meeting.

Three techniques are used for this purpose, the first being most practical. The volume level of the music may be dropped and calls superimposed; or music may be interrupted for calls; or calls may be saved until music program is completed.

In one large aircraft plant, using music at mealtimes only, over 2000 messages are transmitted daily (24 hours), via the plant broadcasting system. They estimated a saving of four minutes on each call. Eight thousand minutes saved means practically 200 hours, which, based on their estimate of $1.50 per hour (supervisory times) means their system earns $350 per day for them. Care should be exercised, however, not to permit unlimited use of a system for paging. It should be used to supplement rather than replace existing facilities.

BASEBALL AND OTHER SPORTS NEWS

The evening meal period is a good time to broadcast big league and local baseball scores. Football scores on Saturday nights are also well received. Horse racing results, except for the Derby, seem to have been disregarded, for obvious reasons. Basketball, and allied sports may be highlighted in areas where they are particularly favored.

OUTDOOR MUSIC

Provision should be made in any plant broadcasting system for coverage of outdoor areas. In pleasant weather, when employees gather outdoors, plant program should reach them there, as well as indoors. Rallies are often best held outdoors in good weather. However, an alternate indoor site should be available for use during inclement weather.

Another value of outdoor music is as a medium for minute safety messages reaching your employees as they enter and leave the grounds. Music thus played outdoors and in employee locker rooms, preceding the opening of a shift and ceasing five minutes before the shift begins, may serve as a time indicator.

MANAGEMENT MESSAGES AND TALKS

These should be brief and infrequent and only on messages of great importance to employer and employee. In fact, a new personality—president, general manager, or works superintendent—heard at periodic intervals has been effective in enabling the employees to get better acquainted with management personnel. Two minutes is a good average for these talks, though three minutes may be used on special occasions, depending on the length of the meal period. Bill Jack, of Jack and Heintz, Cleveland, talks to his associates 24 times a month, he says.

Friendly three-note chimes (manually operated) may be effectively used as a signal preceding plant announcements, messages, etc.

"SAY IT WITH MUSIC"

This radio program, available over the Blue Network, has been useful for the "graveyard," 11 P.M. to 7 A.M., shift. There is a minimum of commercials, done in jingle fashion by the capable Kent-Johnson duet.

SAFETY

RCA Victor has a novel 22-second safety jingle by Messrs. Kent-Johnson, of the Blue Network. This is sent without cost or obligation to any plant requesting it. It may be used by itself or prior to a one-minute safety message by a plant safety director.

Henry J. Kaiser's Portland Shipbuilding Yard says, "RCA sound has been a vital factor in reducing accidents" in their yard even "though their manpower has increased over 500 percent in the past year." (They also tell us that more than one man learns for the first time that he has become a father by hearing of it over the plant sound system.)

WAR BONDS

Experience at RCA Victor indicates that an effective technique for aiding the sale of war bonds is the periodic interview, broadcast to the plant, by a mother or father employed there. The script is brief and written in question-and-answer sequence. The gist of it is that a mother, on being questioned as to why she is buying war bonds, says—(mother being interviewed).

"Why are you buying bonds, Mrs. Smith?"

"Well, sir, you know my Eddie. Nearly everyone in the plant here knows and loves him like I do."

"Yes indeed, Mrs. Smith, and we're proud to hear of another of our boys doing so well in action."

Mother: "You know that word 'action' reminds me of what Eddie wrote Pa and me last week. He was a good ball player, you know—always said a good offense is the best defense, and all the world loves a winner. Well, Eddie said, 'Thanks Mom and Pa and all my friends for your help—we need it. Those bonds give us the baseballs we need. You make 'em over there and we'll toss 'em right smack into the face of those Nazis. And, Mom, off the record, my pitchin' is as good as ever. Keep up the good work. Buyin' bonds gives us the stuff we need.' "

One Admiral in a large United States Navy Yard recently wanted to test his plant broadcasting system. He set a quota of $100,000 in bonds for the yard. The system was used extensively to determine its selling efficiency. Over $492,000 in bonds were subscribed to as a result of the messages on this subject broadcasted to the yard.

HEALTH

The Todd Erie Basin, Brooklyn, New York, found that frostbite was causing many lost man-hours. A daily message broadcast during the cold spell told all men on the night shift that ear muffs were available at the safety shop, and should be worn at all times. In another case of a medical emergency a serious situation was corrected completely within 15 minutes by a message broadcast to all workers.

EMPLOYEE TURNOVER

It has been said that "morale is a state of mind." Workers, despite the importance of their work, may become despondent if rejected by the Armed Services for any reason. In such a case, a Todd worker received a letter from his brother, Joe, telling him not to mind the turndown. Joe and his buddies understood that the boys needed the ships Todd was working on to get across, and, without the help of the fellows in the yard to give them the ships, they wouldn't ever get a crack at Hitler. The brother brought Joe's letter to the yard, and in an interview, read it over the plant broadcast system. The importance of such a human document cannot be overestimated.

CONSERVATION

"Getting in the scrap" and "scrap is all around you" may have become a little trite, so RCA recently introduced Sandy MacShaw—kilts, bagpipe and all. Because Sandy couldn't be every place at the same time, Scotch music

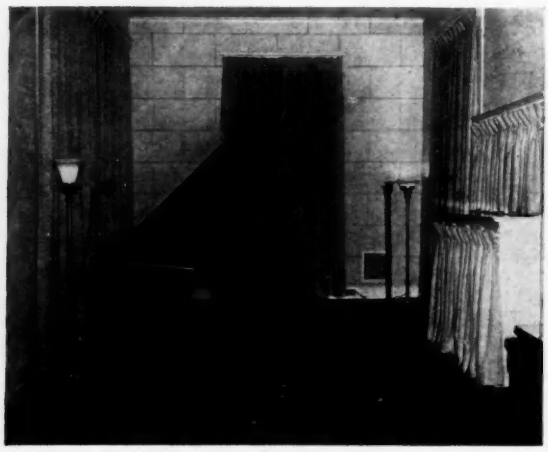


FIG. 1. Modern plant broadcasting studio of the Botany Mills, Passaic, New Jersey. Note acoustic treatment.

was broadcast throughout the plant as a reminder of the conservation drive under way. Every day of this week was devoted to saving manpower, materials, time, etc. Sandy's dialogue, broadcast at meal times, featured such Scotch scripts as, "Care saves wear," etc.

PUNCTUALITY

At RCA Victor, where war bonds and kits for the wife are awarded to workers for "on the job consistency," and the names of winners each week announced over the plant sound system, the rate of absenteeism is down to 2 percent in one plant, with a maximum of 4 percent in another of its plants. Plant officials said that it is difficult to say how much sound or music contributed to this record, but also they have no way of knowing how much higher the absenteeism percentage might be if broadcasting were not used. They cite a case in a department where work was completely stopped for a minute's message to employees on this subject, and emphasize that, to be fully effective, messages must be frequent, although they do not necessarily require a pause in productive activity. Experiments are now being conducted on the use of messages while the workers continue with their work, as well as during non-work mealtime periods.

RECORDED MESSAGES

This medium must be carefully prepared and cautiously used. Standard radio technique, even with "names," has not been wholly practical if level of speech or conversation varies, if tempo is too rapid, or if the speaker talks over the heads of the workers, used a "patent medicine" brand of delivery or is too suave and polished.

Workers like to hear brief, down-to-earth language, and resent high-toned drawing room speech mannerisms.

SPOTLIGHT SERVICE

The Botany Worsted Mills in Passaic, where music is heard in noise levels of from 65 to 102 db, spotlights plant events over its plant broadcasting system (Figs. 1–3). Charles F. H. Johnson, Jr., Vice President of Botany, said they were surprised at the large employee response. The results invariably will please the most skeptical. Incidentally, Botany advised the WPB that music had materially improved their morale and productive efficiency.

ACOUSTIC CONDITIONS

The need for acoustic consultation in relation to factory, office, and cafeteria use of music is increasing daily. It is a problem to tax the skill and ingenuity of the acoustical engineer as well as the architect. Just as theaters "wired for sound" had to undergo room acoustic improvements, so certainly will plants of tomorrow have to improve their space acoustics in order to take full advantage of the unusual reproducing systems and other sound equipment associated with

FIG. 2. Botany employees broadcast their own mealtime programs daily.

bringing electronics—sound—television to industry.

CONCLUSION

In conclusion, we might say that from the time of the pyramids, to the building of ships to sail the seas and skies, music has lightened men's labor.

The impact of war, and its demand for greater productive output from all RCA plants, has resulted in an increase in the production of war material, for the first six months of 1942, of over 42 times that of the corresponding period in 1941. How much sound or music has contributed to this increase is anyone's guess. We do believe, however, that improved worker spirit and enthusiasm from music, as one phase of our own "beat the promise," War Productive Drive Campaign, has enabled each worker to contribute more fully in this vital war effort. At our Harrison plant, sound and music have been used for over ten years. Management there feels that music has been an outstanding aid to our production efficiency, although they say that, without question, music's relation to morale is its number one value.

The many new and interesting facts about music and sound indicate a promising postwar opportunity for those industrial firms unable to benefit by music's values to date. In this postwar era, workers may hear an interview with Mrs. Brown, being broadcast over their plant system and telling why she finally bought a competitive product instead of the product made by those workers. Certainly this will be of interest to the worker and should materially aid postwar "labor-management" committees, dedicated to maintain production.

MATERIAL REFERENCES

Messrs. Harold Burris-Meyer and Raymond Cardinell, Stevens Institute of Technology, Hoboken, New Jersey.

James Thomas Chirug, Boston, Massachusetts (Survey of British Industry).

Messrs. T. F. Joyce, Elmer Morse, Julius Haber, and W. A. Kerr, Radio Corporation of America, RCA Victor Division,* Camden, New Jersey.

Charles F. H. Johnson Jr., Vice President, and T. A. Wardell, Director of Music, Botany Mills,* Passaic, New Jersey.

Billy B. Van, Director of Human Relations, Fellows Gear Company,* Springfield, Vermont.

Mrs. Edith Hough, Frankford Arsenal,* Frankford, Pennsylvania.

John McNeil, WJZ, New York.

Wm. Jack, Jack & Heintz,* Cleveland, Ohio.

Wynford Reynolds, British Broadcasting Company, London, England.

Robert Friedheim, NBC, New York.

FIG. 3. T. A. Wardell, Director of Music, Botany Mills, Passaic, New Jersey, is shown with his aides in the broadcasting control room of the Botany Mills.

Robert D. Potter, Science Editor, 235 East 45th Street, New York City.

Dorin K. Antrim, Stony Brook, Long Island.

G. W. Crawford, RCA Victor Division,* Harrison, New Jersey.

Wyatt & Langdon, Medical Research Council, London, England.

Thomas V. Kennedy, Todd Shipyards,* Erie, Basin, New York.

Edgar Kaiser, Oregon Shipbuilding Corp.,* Portland, Oregon.

Wheeler Beckett, War Production Board, Raleigh Hotel, Washington, D. C.

Sam Tyndall, Curtiss Wright Corporation,* Propeller Division, Caldwell, New Jersey.

O. H. Caldwell, *Radio Today*, 480 Lexington Avenue, New York City.

Frank P. Schuld, Davis & Geck, Brooklyn,* New York.

John C. Apsley, *Industrial Relations Handbook*, Dartnell Corp., Chicago, Illinois.

* User of plant broadcasting and music.

Music as a Safety Factor

EDITH HOUGH
Frankford Arsenal, Philadelphia, Pennsylvania

RELIEVE the mental strain and fatigue of workers on repetitive operations in shops, and you can fully expect to increase production and safety. Music is being found an effective means of accomplishing these results, as a number of tests in various industries have indicated.

At Frankford Arsenal in Philadelphia, one of the country's six old-line arsenals, music has been tried out in several shops with gratifying results. Not only is the effect of music evident in production efficiency, but music of the right type, played at the right periods, and under the right type of control, is found to reduce accident proneness on the part of employees.

It was in connection with this factor of safety that experimental work in music was taken up at Frankford Arsenal by the Safety Section. To give the music as fair a chance as possible, charts were first made in two different shops to discover at just what times during the day the workers were more fatigued and consequently more accident prone. In making this study, no records were made of the work production of individual employees, but merely of the operation of the machines. The resulting charts of machine operation were used in no other manner than as a guide for music installation and programming.

One shop studied contained 85 percent female employees doing fine assembly work at tables; the other had 50 percent male and 50 percent female employees doing very heavy work and operating such machines as Cleveland automatic screws, draw presses, lathes, and milling machines. The two shops thus offered a good contrast in working conditions and working attitudes.

On the basis of the fatigue curves, the following time schedule for the music programs was developed for the two day shifts, that is, for the 7 A.M. to 3 P.M. shift, and the 3 P.M. to 11 P.M. shift:

5 minutes before and after change of shift;
15 minutes during the middle of the shift, in the rest period;
during the entire lunch or supper period;
15 minutes during rest period.

This program was altered for the night shift so that music would be played 10 minutes of each hour during the night from 11 P.M. to 7 A.M.

An important feature of the music installation was that all music was arranged on a planned program basis and maintained under the supervision of one individual.

There was of necessity a short experimental period after the installation of the music programs when various changes and adjustments were made based on the observation of reaction of employees, their indicated choices of program type, and a needed redistribution of amplifiers for better audition. After the music had been in good operating order for three months, another chart was made to determine the results achieved.

Production figures had shown a decided increase. Obviously it is difficult to assign a definite percentage of increase attributable to music, because other factors of necessity enter into such a study. It is felt, however, that this improvement was due to a considerable extent to the planned music program.

Accident reduction was likewise gratifying. It may be said that during the three months of music transmission in one shop the accident reduction was as great as 35 percent, although here again other contributing factors must be taken into consideration.

It is clear to those who have worked on this project at Frankford Arsenal that in the shops where planned music programs are in use, music has relieved fatigue and rendered workers less accident prone. From this viewpoint music can be considered an effective industrial safety measure.

Attitudes Toward Types of Industrial Music*

W. A. KERR
RCA Victor Division, Radio Corporation of America, Camden, New Jersey
(Received June 1, 1943)

IN the early days of plant broadcasting, musical programs for factory workers were largely unplanned and the average employee had little influence upon the selections. The investment by well-meaning employers in electronic know-how and products was not paralleled by an investment in psychological know-how in adjusting the use of a broadcasting system to the human factor—the individual worker.

As a result of these inefficiencies in use of plant systems, some of the potential value of the broadcasts was lost. RCA Victor has recognized the need for psychological measurements and, utilizing professional assistance, is in the process of setting up an industrial music research program. A preliminary task for such research has been that of developing appropriate instruments and measuring the music preferences of industrial workers.

This paper attempts to present, as briefly as possible, some examples of attitude measurements of four different music audiences. Whether these four groups are representative of the occupational populations from which they are drawn is unknown, but the measurements obtained are reported for their possible indicative value. Already we have additional data from several different factories, but time did not allow their analysis and inclusion in this paper. The data here reported do furnish some validation evidence for the "Attitudes Toward Music" scale, a psychological instrument which we have developed, and do provide substantial evidence that various business and industrial groups differ significantly among themselves in the types of music preferred.

The four groups portrayed in the first fourteen figures—the 19 RCA Glee Club singers at Indianapolis; 30 Camden, New Jersey, stenographers; 104 Chicago office workers and warehouse clerks; and 40 Newark, New Jersey, workers in a lamp factory, work in offices or plants now supplied with industrial music and the relative preferences expressed are for "music-while-you-work."

Figure 1 shows that all groups like patriotic songs but that the stenographers and office workers are somewhat less favorable than the Glee Club and the factory workers. As shown by position with relation to the horizontal broken indifference line, the two white collar groups in Fig. 2 actually dislike fast dance music. Perhaps

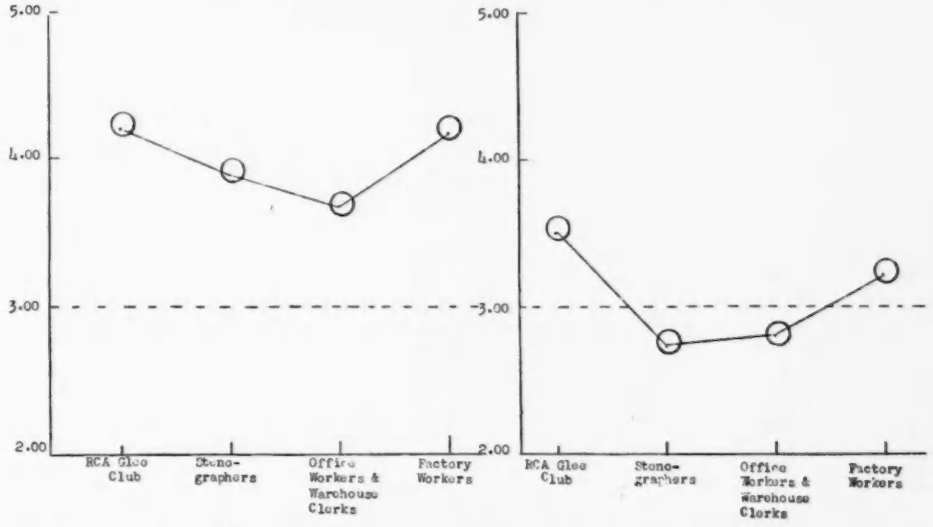


FIG. 1. (left) Average attitudes of four industrial groups toward patriotic songs.

FIG. 2. (right) Average attitudes of four industrial groups toward fast dance music.

* Presented before the Acoustical Society of America, Hotel Pennsylvania, New York, May 14, 1943.

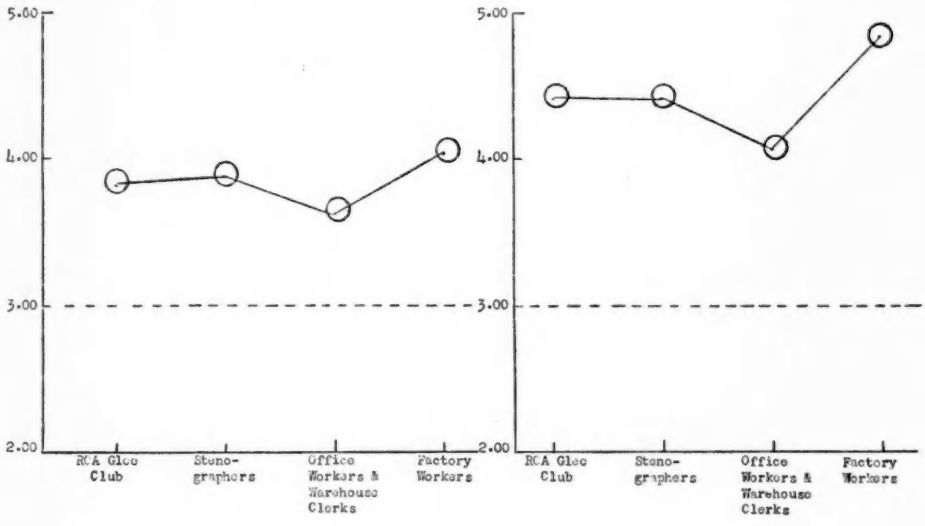


FIG. 3. (left) Average attitudes of four industrial groups toward Hawaiian music.

FIG. 4. (right) Average attitudes of four industrial groups toward popular "Hit Parade" music.

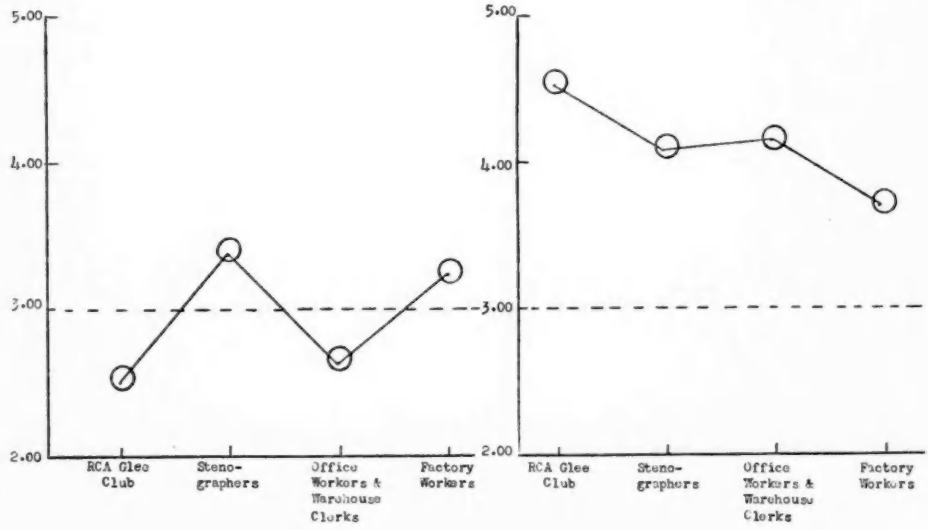


FIG. 5. (left) Average attitudes of four industrial groups toward humorous and novelty music.

FIG. 6. (right) Average attitudes of four industrial groups toward semi-classical and standard music.

this is due to a general tendency for office people to be annoyed by stimuli which may furnish auditory distraction rather than a pleasant psychological atmosphere.

All four groups have a moderate liking for Hawaiian music with the factory group most favorable of all toward this predominantly "sweet string" type (see Fig. 3). Hit parade music (Fig. 4) is the favorite single type with the stenographers and the factory workers, although it is less popular than waltz and semi-classical types among the office-warehouse group. It should be noted, of course, that, relative to the indifference line, hit parade music stands extremely high with all four groups.

Figure 5 suggests a possible regional difference since both of the eastern groups, the stenographers and the factory workers, are more favorable toward humorous and novelty music than are the two mid-western groups. The same tendency is found for attitude toward hillbilly and western music. This evidence is not enough to conclude that a real regional difference exists when other factors are held constant, but it does support the need of our plan of systematic evaluation of regional differences. All groups (Fig. 6) like semi-classical and standard music and there seems to be a tendency for appreciation of this type to be correlated with socio-economic status. The Glee Club and the Chicago office-

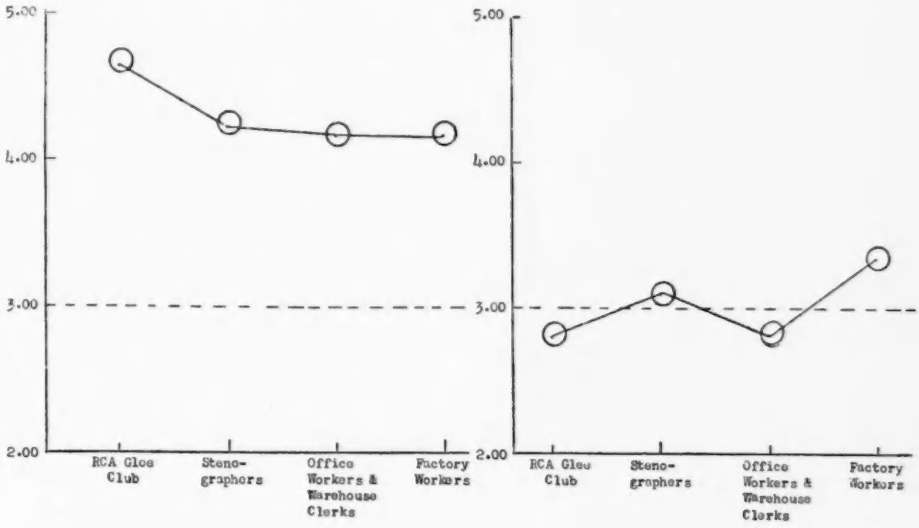


FIG. 7. (left) Average attitudes of four industrial groups toward waltzes.

FIG. 8. (right) Average attitudes of four industrial groups toward polkas and square dances.

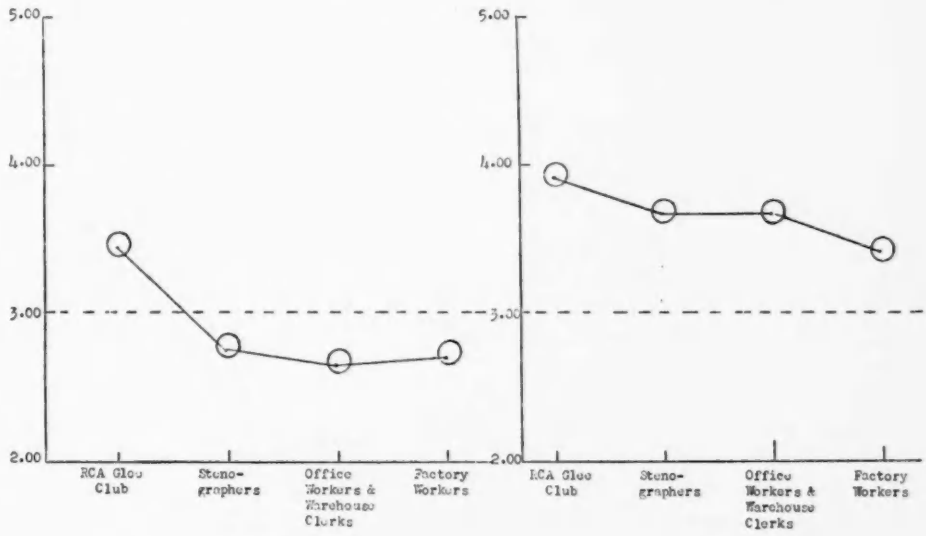


FIG. 9. (left) Average attitudes of four industrial groups toward Negro spirituals and blues.

FIG. 10. (right) Average attitudes of four industrial groups toward marches.

warehouse group rate this type above hit parade music.

Waltzes (Fig. 7) are practically as popular as hit parade music and, in fact, are rated higher than hit parade music by the Glee Club and the office-warehouse group. These four groups respond rather indifferently to polkas and square dances (Fig. 8), although the factory worker group is more favorable than other groups toward this general type. Breakdown of this attitude reveals that all groups are slightly more favorable toward polkas than toward square dances.

Only the Glee Club, as a group, is favorable toward Negro spirituals and blues (Fig. 9). Figure 10 indicates that all groups are moderately favorable toward marches and the trend of mean ratings suggests that liking for marches may be related with socio-economic status.

No group, although the factory group is almost indifferent, is unfavorable toward classical music (Fig. 11). The Glee Club rates classical above both semi-classical and hit parade types, while the stenographers and the office-warehouse group like classical better than nine other types during the work period. Figure 12 reveals extreme disagreement in preference among the four groups for hillbilly and western type music. The factory group is significantly favorable toward this sentimental folk-type music, the office workers and warehouse clerks are rather un-

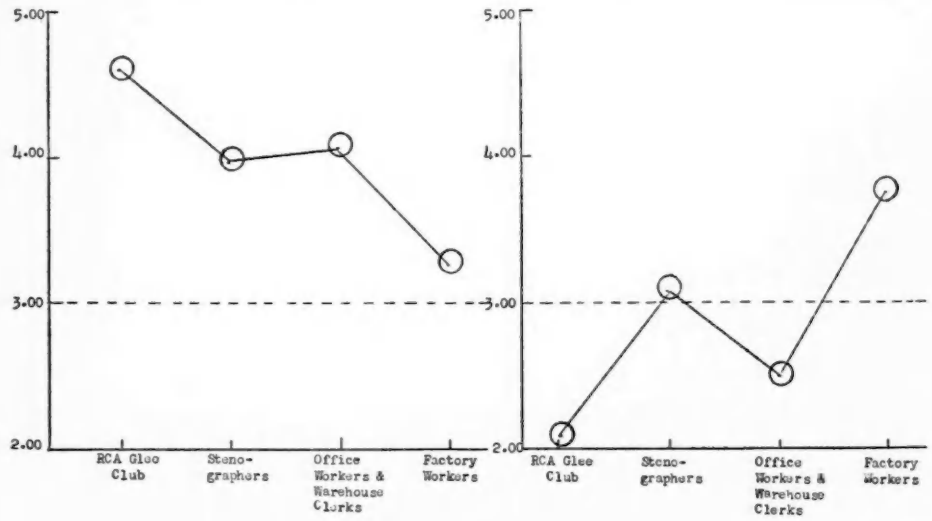


FIG. 11. (left) Average attitudes of four industrial groups toward classical music.

FIG. 12. (right) Average attitudes of four industrial groups toward hillbilly and western music.

favorable, the stenographers are indifferent, and the Glee Club is definitely unfavorable.

The Glee Club and the factory group like sacred music during working hours, the stenographers are almost indifferent, and the office-warehouse group is indifferent (Fig. 13).

Reviewing a summary (Table I) of the responses of four groups toward thirteen types of music reveals data which support the validity of the instrument used. One would expect an adult Glee Club to be composed of individuals with critical and rather well-crystallized attitudes toward various types of music. The fact that the range of type preferences is greater for the Glee Club than for any other group supports this expectation. It is significant to note that no two of these groups fall into the same pattern. In one Pennsylvania factory, Hawaiian music has the second highest mean rating and in a Texas factory just surveyed, patriotic songs score above all other types.

The figures which follow will report the mean attitudes of six groups toward six types of folk or near-folk music.

Western music (Fig. 14) is regarded with mild favor or indifference by all groups except in the Texas gage and machine shop, which tends to be slightly unfavorable. Here again is evidence that common-sense judgment on program planning must yield to an attempt at scientific audience management. It seems practically impossible for any one person, no matter how learned that person is in music, to guess the music preferences of any sizable group of industrial workers. This point is further supported by the fact that the New Jersey lamp workers are more highly favorable toward hillbilly music (Fig. 15) than any other group.

Most of these groups are rather indifferent toward negro spirituals (Fig. 16) with the Glee Club showing greatest appreciation for this type. Blues music as shown by Fig. 17 is regarded with moderate favor by the Glee Club and by all three factory groups, while the two more characteristic white collar groups are relatively indifferent toward the Basin Street classics.

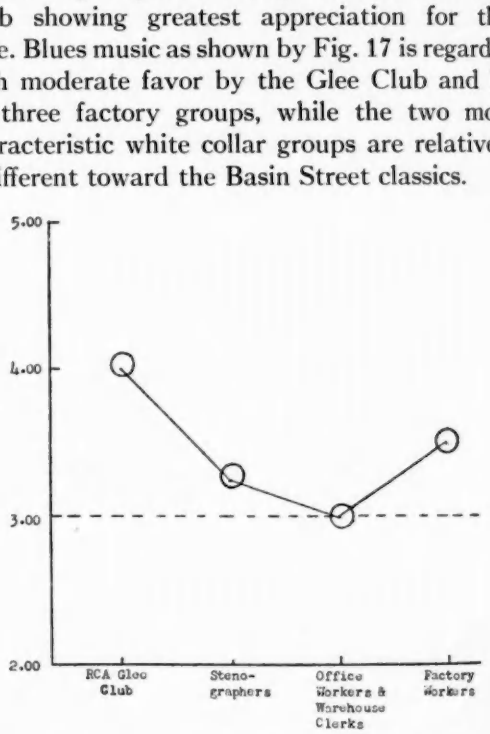


FIG. 13. Average attitudes of four industrial groups toward sacred and religious music.

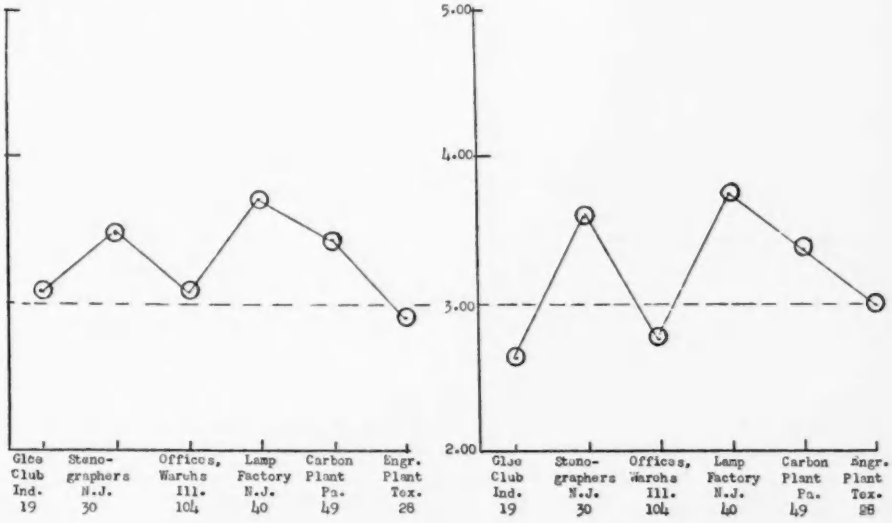


FIG. 14. (left) Average attitudes of six industrial groups toward western music.

FIG. 15. (right) Average attitudes of six industrial groups toward hillbilly music.

It is not surprising to find that of all groups represented here, the group of Pennsylvania factory workers is most favorable toward polkas (Fig. 18). It is possible that this high rating is influenced by provincial pride in the *Pennsylvania Polka*. The stenographers and the office-warehouse group tend to be slightly unfavorable toward polkas. Square dance music (Fig. 19) is liked moderately by the Pennsylvania factory group, regarded with indifference by the New Jersey lamp workers, and disliked by the other groups.

TABLE I. Average attitudes of four industrial groups toward thirteen types of music.

RCA Glee Club	Stenographers	Office and warehouse workers	Factory workers
5.0	5.0	5.0	5.0
			Hit Parade
Waltzes; classical			
5.4 Semi-classical	4.5	4.5	4.5
Hit Parade	Hit Parade		
Patriotic	Waltzes	Waltzes Semi-classical	Patriotic; waltzes
4.0 Sacred	4.0 Semi-classical	4.0 Hit Parade; classical	4.0 Hawaiian
Marches	Classical		
Hawaiian	Hawaiian	Patriotic	
	Patriotic	Marches	Hillbilly, western
	Marches	Hawaiian	Semi-classical
3.5 Fast dance	3.5	3.5	3.5 Sacred
Spirituals, blues			Marches
	Humorous, novelty		Humorous, novelty Polkas, squares; classical
	Sacred		Fast dance
	Polkas, squares		
3.0	3.0 Hillbilly, western	3.0 Sacred	3.0
Polkas, squares	Spirituals, blues	Fast dance Polkas, squares	
	Fast dance	Spirituals, blues	Spirituals, blues
		Humorous, novelty	
2.5 Humorous, novelty	2.5	2.5 Hillbilly, western	2.5
Hillbilly, western			
2.0	2.0	2.0	2.0

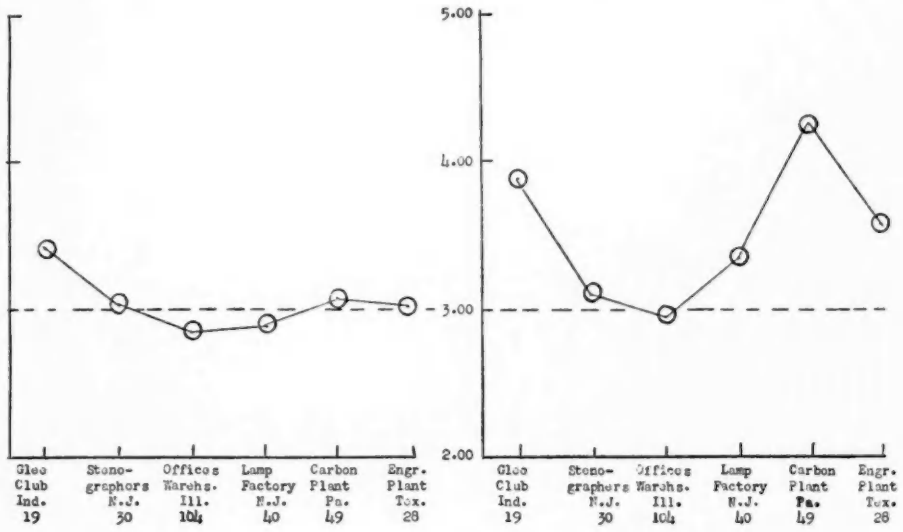


FIG. 16. (left) Average attitudes of six industrial groups toward spirituals.

FIG. 17. (right) Average attitudes of six industrial groups toward blues music.

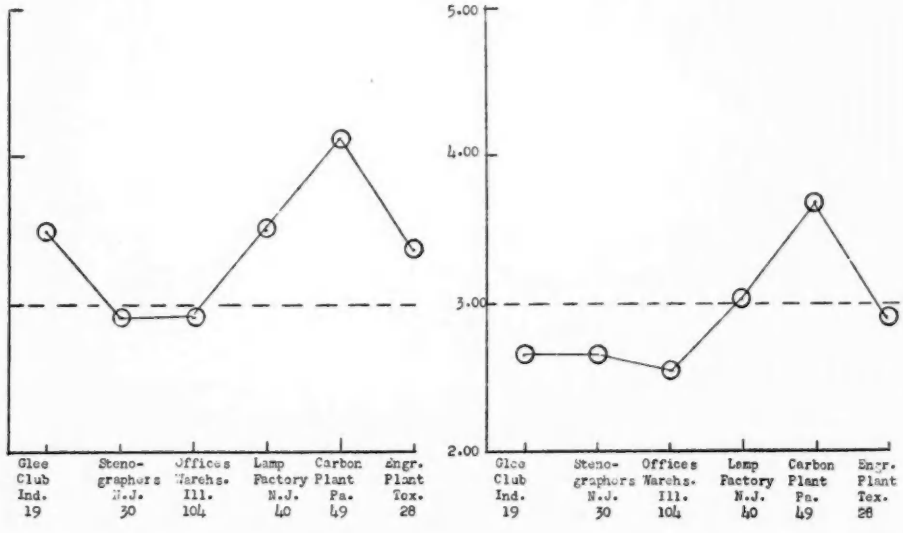


FIG. 18. (left) Average attitudes of six industrial groups toward polkas.

FIG. 19. (right) Average attitudes of six industrial groups toward square dance music.

Thorough description of the instrument used in this study will appear as a validation article at a later date in an appropriate scientific journal. Some conclusions from these preliminary findings may be stated thus.

1. Attitudes toward specific types of industrial music differ considerably for various business and industrial audiences.

2. A given type of music may be liked by one audience but actually be disliked by another audience.

3. Consideration of employee attitudes must be regarded as a definite variable in the development of scientifically planned programs for industrial music audiences.

Programming Music for Industry

BEN SELVIN
Muzak Transcriptions, Inc., New York, New York
(Received June 3, 1943)

THE ideal industrial-music program should incorporate two purposes. One, it should attempt, at all times, to please the greatest number of employees. And two, it should "do a job," to to speak, for the management.

In accomplishing these purposes, three factors must be taken into consideration.

1. Are the workers doing precision or non-precision work?
2. What are their ages?
3. What are their nationalities?

When these facts have been established and we have the composite picture of the worker, we go on from there to build the best possible music-in-industry program for his entertainment and stimulation. To do this, we must consider the following elements: All are vital in arranging the music groups.

1. What to play.
2. How to play it.
3. When to play it.

Under the first heading . . . "What to play" . . . we consider it important to play the type of tune the "man on the street" understands. A program built on such a principle will include current popular tunes, a sprinkling of old-time favorites, Viennese waltzes several times a day, a Latin-American tune about once an hour and a fairly large dose of "Americanized" polkas. In the latter group, you have a tempo that creates a "lift" and is enjoyed by people of all nationalities. An occasional operatic selection is acceptable but it must be a familiar melody, such as the Sextet from "Lucia," the Quartet from "Rigoletto" or the Soldiers' Chorus from "Faust." Throughout this question "What to play," it is important to remember that good industrial music must be transcribed music. No one orchestra has the variety or comprehensive library that can be found in a recorded library where specialists in all types of music have been obtained. A good Latin orchestra, as a rule, cannot play a bright Viennese waltz. Neither can a swing orchestra play a sweet concert arrangement without adding a battery of strings. Therefore, in order to avoid monotony, we are able to furnish, through a good transcribed library, the best of Latin music played by an authentic Latin orchestra, the best Viennese waltzes by experts of this continental type . . . and so on down the line.

Under the second heading . . . "How to play it" . . . we have a very important item in good industrial-music programming. Remember, these people hear plenty of music at times other than their working periods, coming from either phonograph records, radio programs, or live shows. In all cases, what they hear on the outside, as a general rule, are super-duper special orchestrations which were designed to attract attention.

When I was recording director for a prominent recording company, I learned that it was imperative to make arrangements that would be startling in their openings, would include a change of color every twenty or thirty seconds, a change of key between choruses, and sometimes even a change coming in the middle of a chorus. A vocal refrain, plus a fancy ending was almost a "must."

Quite the contrary in good industrial programming. This should be, first of all, strictly instrumental . . . and never over-arranged or tricky.

Not so long ago, I had occasion to visit a plant that was using music furnished by a juke box. While listening, I stood next to a worker who was humming the melody of the particular tune being played. In the middle of the refrain, the orchestra leader decided to switch keys, with the result that the worker stopped short in his singing and remarked: "The dirty so-and-so double-crossed me! Just as I was having a swell time singing the tune I like, he did something that put me all off!"

Remember, these folks are not musicians and do not understand tricky modulations. These trick arrangements are purely juke box and

commercial radio technique. They are absolutely no good for "music in industry."

We at Muzak insist that our orchestras eliminate all the "fancy lace," creating, instead, a type of music that is custom-built for each hour of the working day.

As to the actual building of the music group, the first and last number should be a familiar one. And each group should start at a subnormal level. Bear in mind . . . the people at their machines or desks do not see the orchestra leader and his down-beat. It is advisable, therefore, to begin the first number of each group very quietly and after five or ten seconds, the level can be raised to normal for the duration of the group. Otherwise, it is like plunging into a pool of cold water. The shock is frightening.

Under the heading . . . "When to play it" . . . I want to note this word of warning: "Don't play too much music!" An over-dose is a mistake and more serious than not playing enough. Make the worker ask for it! Two and a half hours of music during an eight-hour working day has been proven to be about right. We recommend, too, that no music be played when the bell rings and the workers start at their jobs. However, the playing of bright music fifteen minutes before the work-day begins proves a stimulant and puts the worker in a good frame of mind. Playing music simultaneously with the start of the shift suggests a speed-up and may be resented by the employee.

The luncheon program should be "The people's choice." By that I mean, the selections played are those that have been requested by the worker. The requests, however, should represent the majority rather than the individual, and should not be played at the specific time requested. The FCC has issued a communique stating that a tune played at the requested time may act as a signal for sabotage.

Care must also be taken in granting some of the requests made by employees. In many instances, they will ask for certain "hot" tunes they hear on juke boxes. Experience has proven that these are not good for them or for the management. By calling specific attention to one particularly sensational number, you are defeating the all-important purpose of "music-in-industry." That being . . . to help the worker along with the job. We must be especially careful not to distract his attention from the work-bench or endanger his physical safety by calling him away, mentally, from a powerful or dangerous machine. Music furnished for industry should be, at all times, a SUBTLE influence.

The recording ban is having a temporary effect in the development of "music in industry." But, as necessity is the mother of invention, we recently recorded a harmonica orchestra in a series of new popular tunes. These have proven to be a real boon to our programs. The effect of several harmonicas, well played, is a novel change from the usual tones emanating from woodwinds, strings, and brasses.

Since its inception, much has been accomplished in the study of "music in industry," but there still remains a vast, unexplored, and constantly intriguing field for study, of which we at Muzak are ever aware. For instance, we recently commissioned several composers to write special industrial music. These writers have been taken through various plants and will compose with a good understanding of the need of the workers and the employer's problem. Here, we believe, is a new field for composers as well as an interesting line of possibilities for us. This, along with numerous other stimulating ideas, makes our work at Muzak (and especially mine, I believe) one of the most enlightened and far-visioned of this day.

The Statistical Method in Determining the Effects of Music in Industry*

R. L. CARDINELL
Stevens Institute of Technology, Hoboken, New Jersey
(Received June 15, 1943)

IN the past year the use of music in industry has increased at an enormous rate. It is hard to say exactly how many plants there are today playing music to their employees, as the number is increasing daily. A year and more ago there were a few musical programs employed in this country, but they did not achieve any great publicity, perhaps because it was not wanted. Consequently, the term "music in industry" referred to employee organizations such as glee clubs or orchestras.

The picture today is quite different. The question no longer is "What is music in industry and what will it do for me," but "How can I get it when I can no longer obtain the equipment?" In other words, music in industry today is pretty generally an accepted fact and as such we will leave it.

There are still many questions to be answered, however, and among these are what it does, what it can do, and why. Many people have attempted to attack these problems by subjective methods. Asking the employees and management for their respective ideas about music in industry gives rise to many diversified replies, subject to variation according to the manner in which the questions are asked. Individual preferences are important but must be used with discretion in making industrial programs. What is needed is some definite measure of performance that may be used as a standard of comparison.

A little over two years ago at Stevens we embarked on the study of music in industry as a corollary to the general problem on which we were working at the time. This, of course, was previous to America's entry into the war. The first phase of the study consisted of compiling a bibliography of physiological and psychological data, and anything that had ever been written about industrial music. Strangely enough, or shall I say naturally enough, we found that there was very little original material available, and as each author quoted someone else, the whole search went merrily around in a circle.

We did emerge with a few basic ideas, however. The most important of these is that the primary effect of music in industry is to relieve fatigue and boredom. This has been definitely proven in psychological laboratories, but to find a practical index in a factory is quite another matter. After searching in vain, we decided to measure the variation of output as being a secondary effect of a musical installation, and one which would be easy to measure. We also recorded other factors which we thought might show a change. Among these were absence rates, lateness, rejects, and fake illness. Of course, since our entry into the war, everyone has been interested in production.

It was assumed at the beginning of our studies that the plants kept production figures and that we would have no trouble in determining just what the music had done to these figures. We soon learned, however, that while most plants were more than willing to let us examine their production records, these records were not kept in a form that was convenient to show us what we were looking for. The total production, alone, of a plant or a department, is not sufficient, and it therefore became necessary to take original data on production, or go into involved calculations on the plant records to obtain the factors we desired.

In order to show specifically what music has done to production the figures should be calculated to a common base of man hours. This may be man hours per unit, units per man hour, units per 100 man hours, or any convenient factor.

Theoretically, the production of each individual employee should be taken on this basis and conclusions drawn from the totaled results. However, to do this involves a great deal of time and expense. A more convenient and fairly accurate way of getting at the facts is to follow the production of a sample group of employees.

* As presented at the Acoustical Society of America symposium on Music in Industry, New York City, May 14, 1943.

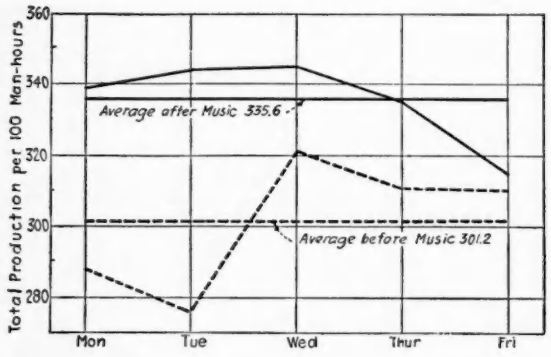


FIG. 1. Production per 100 man hours, one week before and one week after music installation.

This group should be composed of at least fifteen or more individuals picked at random from those employees who are thoroughly experienced in the work which they are doing.

Figure 1 is an example of production plotted against man hour units. Total production is not sufficient because it does not take into consideration variations in attendance, primarily, nor other changes which may have some effect. Among these are weather, lighting, and machine placement. The plant management may say that production is up 15% since the installation of music, but an investigation may show that the number of employees has increased 10%, better lighting has been installed, and the building has received a new coat of paint. It is only when production is based against a man hour unit and control exercised over other variable factors that the result becomes valid.

In the same way the factor of attendance should be treated. The number of absences should be plotted against the *total number* of employees on the pay roll. Accident rate should be correlated to both production and total personnel.

As I mentioned before, there are other factors which affect production which might have been introduced somewhere between the "before and after" comparison periods, and it is advisable to keep these well in mind before making any statements as to what music has or has not done. It is generally found that production varies with the day of the week, and the employees on piece rate usually have a much higher output on the last day of their fiscal week than on any other day. Referring again to Fig. 1, although pay day was Friday, wages were computed on a Thursday through Wednesday basis, and you will note that starting with Thursday there is first a falling off of production, then a rise immediately preceding the end of the week. It therefore becomes necessary to use identical days of the week in making comparisons.

Allowance must also be made for weather. Naturally, it is impossible for an investigator to command the weather to remain constant, but it is advisable to choose for data-taking periods those in which the weather remains reasonably uniform. In Fig. 1 you will notice that the "after music" curve shows a drop on Friday much greater than the "before music" curve. This drop was due to the fact that that particular day was very depressing, compared with the other days in either week.

We have received a great deal of correspondence from plants requesting advice on how to go about making up a musical program, and the best we can offer on this subject is that each plant should be treated as an individual case. The most effective way of planning the program is by means of a statistical study throughout the day. This requires taking output figures every ten or fifteen minutes to determine what is commonly known as a fatigue curve. I have found that it is not sufficient to take the output of an employee at a three- or five-minute stretch at frequent intervals, as the production figure so obtained can be rendered invalid by minor variations of the work rate. On the other hand, if total production from the beginning of the day is taken at definite intervals, the output registered is the accumulating total and is not affected

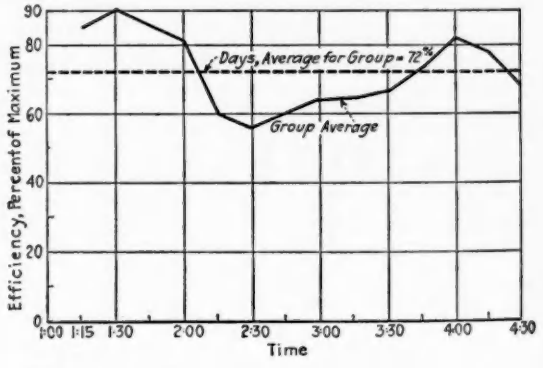


FIG. 2.

by variations induced by the sight of a stopwatch.

Having obtained a fatigue curve by this method, the program is planned to knock the dips off the bottom. The following two curves will illustrate to some extent what may be accomplished by this method. Figure 2, though for a specific day, shows a condition that was present in all "before music" charts made in the plant in question. There is a large dip beginning about 2 o'clock in the afternoon. (The dotted horizontal line defines the area under the curve, which is the index for the daily total of production.) A suitable musical program was developed, with the sole purpose of attacking the dip in question, and Fig. 3 shows the result. The dip was reduced approximately 30% and the day's production was increased 14.8%.

The charts are for identical days of the week, weather conditions were uniform, and no changes had occurred in the plant. The result in this particular case is unusual, but increases in production between five and ten percent are fairly common with well-planned programs.

The vertical scale used in these two charts was based on an efficiency figure rather than a straight production figure. This was necessary because, although the employees were operating the same type machines, they were doing different jobs and their production rates varied from one to another. At the end of the day the maximum production interval for each employee was found and was designated as 100% efficient for that day. The production of the other periods was computed as a percentage of the maximum and it thereby became possible to average the results of all the employees studied on the basis of efficiency. It was found that the efficiency curves were practically identical with the output curves for the individual employees.

Enough facts are not known at the present time to do all this the first time. The results of Fig. 3 were arrived at after two or three preliminary programs had been tried. Therefore, we recommend that an individual plant proceed along a trial and error basis, following the results with output studies until maximum efficiency is reached. This may seem at first glance to be an additional expense and burden. However, our feeling has been and still is that an increase in production can be gained through this method

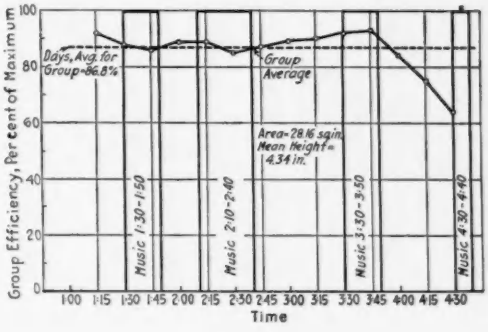


FIG. 3.

which will far outweight the costs involved in developing suitable programs.

Although the original research project at Stevens Institute in Music in Industry was discontinued due to the expiration of its subsidy, I am happy to report that the study is proceeding again, under the auspices of the Office of Production Research and Development of the War Production Board. The primary objectives are to determine the most suitable programs for specific operations and conditions, and to compile acoustic qualifications and limitations regarding the use of music in industry. Advice and suggestions are being offered to war plants requesting assistance, so that the results of the research will be of immediate and practical use to industry.

Letter to the Editor

The Editorial Board assumes no responsibility for the opinions expressed in letters.

On Subjective Tones

JOHN D. TRIMMER
708 Florida Avenue, Oak Ridge, Tennessee
June 18, 1943

SIX years ago in this journal[1] the writer joined in deploring loose usage of the term "subjective tone," and in directing very specific and very serious criticism against the procedure called "measuring intensity of subjective tones by the method of most pronounced beats." Except for one lone (but most welcome) corroboratory voice,[2] the complaint evoked only a rather stony silence. Now, however, there has appeared in the journal a paper[3] which reaffirms, with taken-for-granted sureness, the old "unchastened" point of view. This paper is written in blunt disregard of two facts previously pointed out,[1] namely, first, that between the use of an exploring tone to produce beats and the use of an exploring tone to observe steady tone phase effect there is no fundamental difference whatsoever, any more than there is between alternating current of arbitrarily low frequency on the one hand and direct current on the other; and second, that the only logical foundation for the best beat method would be a phase effect that consisted predominantly of a variation in the strength of the one tone being "measured"—something which, if it has ever been observed for subjective harmonics, has apparently not been reported. The degree of disregard is indicated, as to the first item, by this quotation from a paragraph near the end, "This work did not take into consideration any effect of phase on the nature of the subjective tones"; and as to the second item, by the whole paper itself, which is described as a series of measurements of the intensity of subjective tones (including subjective harmonics as well as subjective combination tones) by the best beat note method.

The present writer feels that this criticism of the best beat method, far from being a purely negative thing, is really the key to progress in understanding subjective tones. It is of the most fundamental importance to classify the various subjective tones according to two ratings: one, the pitch perception rating; and two, the phase effect rating. The pitch perception rating would concern the extent to which a reasonable sample of observers would agree in perceiving clearly the pitch of the subjective tone in question. The phase effect rating would concern the extent to which the observers would concur in describing the effect of an exploring tone introduced at the frequency in question as variation in the strength of the one tone. The highest pitch perception rating would undoubtedly go to the first difference tone, perhaps also the highest phase effect rating; for this is a subjective tone which is readily and universally perceived and seems to have most unmistakably an existence "of its own." On the other hand, the subjective second harmonic of a 100-c.p.s. fundamental would receive a low phase effect rating, for, as reported,[1] the phase effect observed by adding a 200-cycle exploring tone to a strong 100-cycle fundamental is "a complicated aural experience, not characterized outstandingly by the variation of the second-harmonic component."

Presumably, subjective tones getting high phase effect ratings would also get high pitch perception ratings, but this is just one of many very interesting questions that could be answered by suitable experiments. It would probably be impossible to establish these two ratings in any but rough, qualitative fashion. Even so, any such classification of subjective tones would be of great help in understanding the differences between the various subjective harmonics and combination tones and in fitting the whole phenomenon of subjective tones into the theory of hearing. In particular, the phase effect rating of a given subjective tone would stand in direct proportion to the justifiability of using the best beat method to measure the intensity of that tone.

[1] J. D. Trimmer and F. A. Firestone, J. Acous. Soc. Am. **9**, 24 (1937).
[2] J. F. Schouten, Proc. K. Akad. Amst. **41**, 1086 (1938); Sci. Abs. A, No. 1323 (1939).
[3] C. R. Moe, J. Acous. Soc. Am. **13**, 159 (1942).

Acoustical Society News

Notice to Acoustical Society Members in the Armed Services

Acoustical Society members in the Armed services may, at their request, have their membership suspended for the duration. Suspended members are not required to pay dues, but they remain on the membership list and receive programs, announcements, etc., but not the Journal. Any member in the armed services who finds himself too occupied to read the Journal may have his membership suspended by writing to Secretary Wallace Waterfall, 120 South LaSalle Street, Chicago, Illinois.

New Members

Thomas Watson Baldwin
107–39 Princeton Street
Jamaica, New York
Physicist
Signal Corps Laboratories, E.S.L.
Fort Monmouth, New Jersey

Thomas E. Caywood
1734 Cambridge Street
Cambridge, Massachusetts
Special Research Associate
Cruft Laboratory
Harvard University
Cambridge, Massachusetts

Dr. Frederick M. Grossman
133 East 58th Street
New York 22, New York
Physician

Marion Hayes Gwynn
Mountain Lakes, New Jersey
Technical Consultant
Box 142
Mountain Lakes, New Jersey

Luther Jones
4833 Tremont Street
Dallas, Texas
Acoustical Engineer
S. W. Nichols Company
209 Exposition Avenue
Dallas, Texas

Ilya Elie Katel
144 West 82nd Street
New York, New York
Occupation: Sound Engineer
144 West 82nd Street
New York, New York

Fitzroy Kennedy
10 Follen Street
Cambridge, Massachusetts
Research Associate
Psycho-Acoustic Laboratory
Memorial Hall
Harvard University
Cambridge, Massachusetts

Richard Butterworth Lawrance
333A Harvard Street
Cambridge, Massachusetts
Communications Engineer
M.I.T. Radiation Laboratory
155 Massachusetts Avenue
Cambridge, Massachusetts

Henry Cowles Littlejohn
39A Lee Street
Cambridge, Massachusetts
Design Engineer
General Radio Company
30 State Street
Cambridge, Massachusetts

George Diebold Miller
274 Senator Place
Cincinnati, Ohio
Chief Engineer
Cincinnati Mgr. Company
Gest & Evans Street
Cincinnati, Ohio

Edward Charles Molina
144 Dodd Street
East Orange, New Jersey
Scientific Staff
Columbia University
New York, New York

Charles Thomas Molloy
19 Woodruff Avenue
Brooklyn, New York
Physicist
Brooklyn Navy Yard
Brooklyn, New York

Louis Edward Murray
Jacobson & Company, Inc.
335 East 45th Street
New York, New York
Research Engineer

Paul Bennett Oncley
1825 Guess Road
Durham, North Carolina
Research Physicist
Duke University
Durham, North Carolina

Charles Hobert Owens
P.O. Box 291
Austin, Texas
Sales Engineer
S. W. Nichols Company
209 Exposition Avenue
Dallas, Texas

George Gust Pagonis
730 Lawrence, N.E.
Washington, D.C.
Assistant Electrical Engineer
Technical Laboratory, F.B.I.
Washington, D. C.

Jacob Monroe Schmidt
Department of Physics
University of Southern California
Los Angeles, California
Physics Instructor

Alexander Ivanovitch Stepanoff
P.O. Box 113
Long Branch, New Jersey
Assistant Physicist

William Morriss Stringfellow
136 Huron Street
Toledo, Ohio
Chief Engineer
WSPD, Toledo, Ohio

Neill Gilespie Wade, III
43 Deforest Avenue
Summit, New Jersey
Engineer
Bell Telephone Laboratories
Murray Hill, New Jersey

William Stewart Wallace
University of Toronto Library
Toronto, Canada
Librarian

Alan Watton, Jr.
Wright Field
Dayton, Ohio
1st Lieutenant, U. S. Army Air Corps

William Wallace Weedfall
Cruft Laboratory
Harvard University
Cambridge, Massachusetts
Special Research Associate

Peter Jocelyn Westervelt
Room 4–139 M.I.T.
Cambridge, Massachusetts
Research

Frederick Elmer White
Box 4362
Duke Station
Durham, North Carolina
Research Physicist
Duke University
Durham, North Carolina

Fellows	162
Members	729
Total membership	891

Current Publications on Acoustics

F. A. FIRESTONE
147 Randall Laboratory, University of Michigan, Ann Arbor, Michigan

Book Review

An Introduction to Biophysics. OTTO STUHLMAN, JR. Pp. 375+vii. John Wiley & Sons, New York, 1943.

The author has undertaken to provide a textbook for students, whose primary interests lie in the biological sciences, who desire an understanding of the applications of physics to biological problems. He has produced a book which should have a wide appeal, as it will also inform physicists as to the nature of some of the biological problems which are explainable in terms of physical principles. His lucid expositions will serve to bring many scientists up-to-date in fields not immediately their own.

The volume may well be considered a companion to the "Recent Advances" series that have proved so useful in the medical sciences. It is a happy combination of a reference book for basic physical formulae and concise expositions of the principles underlying them and also an account of interesting recent advances in biophysics. The free use of excellent diagrams and graphs adds greatly to the ease of understanding.

The selection of topics is a point of considerable interest. The author has included only subjects which are representative of the major subdivisions of physics. Among the chapter titles are the following: "Biophysically active x-rays," "Biophysical characteristics of the eye," "Emission and absorption of biophysically active light," "The structure and properties of surfaces and membranes," "The biophysical problem of nerve conduction," "Auditory biophysics," and "The compound microscope; the electron microscope."

The title of the volume, "An Introduction to Biophysics," raises the question, "what is biophysics"? The author implicitly seems to consider as biophysics all applications of physics to biological problems. This is indeed a commonly accepted definition, and a useful one from the pedagogical point of view if the objective is to teach to students of biology the physics they need for a proper understanding of biological phenomena and also of the tools employed in their study. In many of his chapters, Professor Stuhlman wanders freely from apparatus to biology and back again making no distinction between the two types of problem. But for the dignity of biophysics as an independent academic discipline, the reviewer prefers to consider that biophysics proper is concerned with the interpretation of biological problems in terms of physical principles and not with the mere tools of biological research. For example, the compound microscope, the electron microscope, the vacuum-tube amplifier and the cathode-ray oscilloscope are often used to obtain information pertinent to problems which are strictly biological, such as the number and character of blood cells in certain diseases, or the rate of discharge of nerve impulses from sense-organs. Some knowledge of physics may be necessary for intelligent and effective operation of the apparatus, but it is hardly "biophysics." On the other hand, the optical characteristics of the eye, the acoustic properties of the ear, the origin of bioelectric potentials, the nature of nerve conduction, and the ultra-microscopic structure of tissues are true problems of biophysics. Intermediate, and still legitimately biophysical, are such problems as the biological effects of radiation and the psychophysical problems of sensation in which an external physical agent produces a biological effect and enters as a parameter into the definition of the problem.

Judged by these criteria, one of the truly biophysical chapters in Professor Stuhlman's book, and the one of most obvious interest to readers of this journal, is the one dealing with the auditory mechanism. After a concise summary of the physics of sound waves he considers the problems of the acoustics of the pinna and the auditory canal and the transmission characteristics of the eardrum. Considerable attention is devoted to the ossicles and the relation of their shape, size, suspension, and articulation to their movements and to their transmission characteristics. His description is based largely on his own studies. It is the most complete and up-to-date description available and at the same time is admirably clear and concise. An excellent summary of the mechanics of the inner ear and of the problems of the perception of loudness and of pitch and related topics, such as masking and aural harmonics, is also given. The chapter should be of great value and interest to all who approach the problem of hearing from the physical point of view.

HALLOWELL DAVIS
Harvard University

References to Contemporary Papers on Acoustics

MOST of the titles of papers appearing in other languages than English have been translated. Abstracts in English of many foreign papers have appeared or soon will appear in Science Abstracts, Section A. Where references are made to Science Abstracts, the reference is to the volume number and abstract number. The abbreviations of the names of journals are those used in Science Abstracts and can be found in any annual index to those abstracts.

The numbers appearing at the head of each entry are the numbers which identify the subject headings in the Cumulative Index of this journal issued in November, 1939. The same Classification of Subjects can be found in the index to Volume 14.

Compiled with the generous assistance of Samuel Sass, Physics Librarian, University of Michigan.

---

2. Architectural Acoustics

2.1 **Remarks on the "Oelsner" Building Construction.** G. Hofbauer. Akust. Z. **7,** 111–115 (May, 1942); Wireless Engineer **20,** 1443A (1943).

2.2 **The Improvement of Audibility by Sound Reflectors.** R. Berg and J. Holtsmark. Akust. Z. **7,** 119–120 (May, 1942).

2.2 **Recent Improvements in the Technique of the Acoustics of Rooms.** M. Nuovo. Formacion y Documentacion Profesional (Madrid) **1,** 201 (March/April, 1942); Wireless Engineer **20,** 1448A (1943).

2.5 **Making Light Weight Acoustic Block.** R. S. Torgerson. Rock Prod. **46,** 87–88 (April, 1943).

2.9 **The Sound-Excluding Action of Walls on Speech and Music.** J. Capek. Akust. Z. **7,** 152–156 (July, 1942); Wireless Engineer **20,** 1449A (1943).

2.9 **Theory of Sound Exclusion by Thin Walls for Oblique Incidence.** L. Cremer. Akust. Z. **7,** 81–104 (May, 1942).

4. Ear and Hearing

4.1 **Sound Reception in Animals and Human Beings.** H. Autrum. Naturwissenschaften **30,** 69–85 (Jan. 30, 1942); Sci. Abs. **A46,** 835 (1943).

4.1 **Hearing Ranges of Four Species of Birds.** E. P. Edwards. Aukens **60,** 239–241 (April, 1943).

4.1 **A Simple Method of Measuring Percentage of Capacity for Hearing Speech—Fundamental Factors in Setting Up a Standard.** E. P. Fowler. Arch. Otolaryngol. Chicago **36,** 874–890 (1942).

4.1 **Functional Examination of Hearing.** A. Lewy and N. Leshin. Arch. Otolaryngol. Chicago **37,** 82–107; 242–262 (1943).

4.3 **The Binaural Phenomenon of Bone Conduction; a Tuning-Fork Test.** A. B. Alexander. J. Laryngol. **57,** 411–415 (1943).

4.3 **Some Details in Directional Discrimination in Hearing.** K. de Boer and A. Th. van Urk. Philips Tech. Rundschau **6,** 363 (1941); Wireless Engineer **20,** 1459A (1943).

4.4 For references on Deafness see Volta Review.

4.4 **The Effects on Hearing of Acoustic Trauma in Industry and War.** S. L. Fox. Sth. med. J., Bgham **36,** 97–100 (1943).

4.4 **The Clinical Examination of the Hard of Hearing.** W. Mueller. Ann. Otol. St. Louis **51,** 756–760 (1942).

4.4 **How Little Do We Hear?** W. A. Munson. Bell Lab. Rec. **21,** No. 10, 341–346 (June, 1943).

4.5 **Deaf Rescued; Hearing-Aid Devices to be Standardized.** Business Week 37–38 (Mar. 20, 1943).

4.5 **Electro-Acoustics and Audiometry.** P. Chavasse. Bull. de la Soc. Franç. des Élec. [6] **2,** 341 (Sept. 1942).

4.5 **Presentation of a Simple Device for Excluding Interfering Noises from One Ear While Testing Hearing Acuity of the Other Ear.** H. Newhart. Laryngoscope, St. Louis **52,** 983 (1942).

4.5 **A Hearing Aid Clinic.** B. H. Senturia, S. R. Silverman, and C. E. Harrison. Ann. Otol. Rhinol. Laryngol. **52** No. 1, 131 (Mar. 1943).

4.6 **Correlation of Hearing Acuity for Speech with Discrete Frequency Audiograms.** W. Hughson and E. Thompson. Arch. Otolaryngol. Chicago **36,** 526–540 (1942).

4.6 **Effect of Experimentally Altered Air Pressure in the Middle Ear on Hearing Acuity in Man.** W. E. Loch. Ann. Otol., St. Louis **51,** 995–1006 (1942).

4.6 **Presentation of a Simple Device for Excluding Interfering Noises from One Ear While Testing Hearing Acuity of the Other Ear.** H. Newhart. Laryngoscope, St Louis **52,** 983 (1942).

4.9 **The Perception of Note Pitch.** J. F. Schouten. Akust. Z. **7,** 33–35 (Jan. 1942).

4.11 **Studies in Auditory Theory. II. The Distribution of Distortion in the Inner Ear.** W. R. Thurlow. J. Exper. Psychol. **32,** 344–350 (1943).

5. Applied Acoustics. Instruments and Apparatus

5.1 **Receiver for Sound Signals to Give Warning to Motor Vehicle being Overtaken by Another.** W. M. Hahnemann. Akust. Z. **7,** 159 (July, 1942).

5.1 **Vibration Table for Dynamic Tests in the Note-Frequency Range.** Meister. Akust. Z. **7,** 51–56 (1942); Wireless Engineer **20,** 1548A (1943).

5.9 **Historic Firsts—The Condenser Microphone.** Bell Lab. Rec. **21,** No. 11, 394 (July, 1943).

5.9 **Applications of the Throat Microphone.** J. Shawn. Communications **23,** 11–12 (Jan. 1943).

5.9 **Photo-Electric Torsiograph.** W. SPILLMANN. Schweiz. Arch. Angew. Wiss. Techn. **8,** 252–255 (Aug. 1942); Sci. Abs. **A46,** 88 (1943).

5.15 **Meters for D.I.N. Sound Levels: Committee's Recommendations.** Akust. Z. **7,** 156–159 (July, 1942).

5.15 **The Recording of Rapidly Varying Processes with the Neumann Attenuation Recorder.** M. GOSEWINKEL. Akust. Z. **7,** 104–111 (May, 1942).

5.15 **The Noise Primer, VIII. Maximum Accuracy in noise Measurements.** H. H. SCOTT. General Radio Experimenter **17,** No. 12, 3–7 (May, 1943).

5.15 **The Noise Primer, IX. Vibration and Sound; X. The Vibration Meter; XI. How to Use the Vibration Meter.** H. H. SCOTT. General Radio Experimenter **18,** No. 1, 1–8 (June, 1943).

5.16 **Method for the Microscopic Viewing of Magnetic Sound-Recordings.** H. HEIDENWOLF. Lorenz-Berichte No. 3/4, 119 (Dec. 1941).

6. MUSICAL INSTRUMENTS AND MUSIC

6.1 **Cooperation with the Film Industries in the Study of Primitive Music.** CARL E. SEASHORE. Science **96,** No. 2490, 263–265 (Sept. 18, 1942).

6.1 **A National Bureau of Science in Music.** CARL E. SEASHORE. Music Educators. (Feb. Mar. 1943).

6.9 **Sounds Old and New by Electrical Musical Instruments.** H. BODE. Bull. Ass. Suisse Elect. **33,** 479–483 (Aug. 26, 1942); Sci. Abs. **A46,** 832 (1943).

6.9 **Electronic Musical Instruments and the Progress of the Pipeless Organ.** L. VELLARD. Rev. Gén. de l'Élec. 214–228 (April, 1941).

7. NOISE

7.7 **Vision, Hearing, and Aeronautical Design.** L. D. CARSON, W. R. MILES, AND S. S. STEVENS. J. Aero. Sci. **10,** 127–130 (April, 1943).

7.7 **Probable Cause of Noise in Gyro Instruments and a Suggestion for Its Prevention.** R. G. OJERS. Instruments **16,** 144 (Mar. 1943).

7.7 **How to Make Piping Noiseless.** W. F. SCHAPHORST. Am. Dyestuff Rep. **32,** 170 (Apr. 12, 1943).

7.7 **Study of Machinery Vibration.** H. SEYMOUR. Electrician **129,** 691–692 (Dec. 25, 1942).

9. SPEECH AND SINGING

9.1 **Some Notes for Singers.** JOHN MEWBURN LEVIEN. Novello and Company, Limited, London.

10. SUPERSONICS (ULTRASONICS)

10.1 **Bats and the Scientific Method.** J. MILLS. Amer. J. Phys. **11,** 151–153 (1943).

10.1 **Supersonic Waves: Their Effects and Employment in Various Fields of Modern Technique.** G. OGGIONI. L'Elettrotecnica, 410 (Aug. 25, 1941).

10.3 **A New Sonic and Supersonic Transmitter for the Production of Strong Intensities in Gases.** L. EHRET AND H. HANNEMANN. Z. techn. Phys. **23,** 245–266 (1942); Wireless Engineer **20,** 1453A (1943).

10.3 **A Supersonic-Wave Transmitter Driven by an Arc Generator.** H. H. ZSCHIRNT. Hochfrequenztechnik u. Elektroakustik **60,** 126–135 (Nov. 1942); Wireless Engineer **20,** 1451A (1943).

10.6 **The Propagation of Supersonic Waves in Wires.** E. CZERLINSKY. Akust. Z. **7,** 12–17 (Jan. 1942); Wireless Engineer **20,** 1450A (1943).

11. WAVES AND VIBRATIONS

11.2 **Reflection and Refraction of Spherical Waves: Effects of the Second Order.** H. OTT. Ann. Phys., Lpz. **41,** 443–466 (1942); Sci. Abs. **A46,** 622 (1943).

11.3 **The Dispersion and Absorption of Sound in Clouds.** K. OSWATITSCH. Phys. Z. **42,** 365–378 (1941); Sci. Abs. **A46,** 367 (1943).

11.3 **The Propagation of Sound in the Atmosphere.** E. G. RICHARDSON. Endeavor **I,** No. 3 (July, 1942).

11.5 **The Production of Elastic Waves by Explosion Pressures. I. Theory and Empirical Field Observations.** J. A. SHARPE. Geophysics **7,** 144–154 (April, 1942); Sci. Abs. **A46,** 365 (1943).

11.7 **Vibration of a Thin Vertical Cantilever Caused by a Damped Harmonic Disturbance of the Ground.** M. BORN AND H. L. D. PUGH. J. Instr. Civ. Engrs **18,** 279–293 (June, 1942); Sci. Abs. **A46,** 825 (1943).

11.7 **An Investigation of the Failure of a Single Helical Geared Turbine System Due to Combined Axial and Torsional Vibration.** S. F. DOREY AND G. H. FORSYTH. Trans. Instn Nav. Archit., Lond. **84,** 207–227 (1942); Sci. Abs. **A46,** 827 (1943).

11.7 **Study of Machinery Vibration.** H. SEYMOUR. Electrician **129,** 691–692 (Dec. 25, 1942).

Review of Acoustical Patents

ROBERT W. YOUNG
C. G. Conn, Ltd., Elkhart, Indiana

Printed copies of patents are furnished by the Patent Office at a cost of 10¢ each. Address all communications to: The Commissioner of Patents, Washington, D. C. Remittance may be made by money order, certified check, cash, or special coupons which are sold in blocks of twenty or books of one hundred.

The decimal numbers appearing before titles are those which identify the headings being used in the analytic subject index of this journal. The Patent Office classification given in parentheses with each patent entry is outlined in the "Manual of Classification of Patents" which is obtainable from the Superintendent of Documents for $1.50.

Unless otherwise indicated, patents listed have been issued by the United States Patent Office.

Reviewers

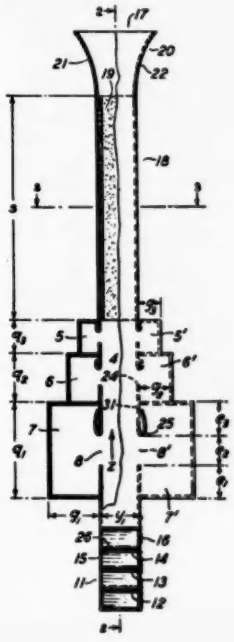
B. B. BAUER, *Shure Brothers, Chicago, Illinois*
H. A. ERF, *The H. A. Erf Acoustical Company, Cleveland, Ohio*
H. S. KNOWLES, *847 Clinton Place, River Forest, Illinois*
C. E. NELSON, *Nelson Muffler Corporation, Stoughton, Wisconsin*
L. W. SEPMEYER, *U. S. N. Radio and Sound Laboratory, San Diego, California*
R. W. YOUNG, *C. G. Conn, Ltd., Elkhart, Indiana*

2,308,886

2.1 ACOUSTIC WAVE FILTER

Warren P. Mason, assignor to Bell Telephone Laboratories, Incorporated.
January 19, 1943, 18 Claims (Cl. 181–48).

The design of an acoustic filter system is disclosed for attenuating certain bands of frequencies in a conduit handling large quantities of air. Oppositely disposed side branches are described and formulae are given for their design. The design of longitudinal partitions is also included for those applications in which the dimensions of the duct and the frequencies to be attenuated require their use. The description refers to an air conditioning system and the acoustic filter is introduced between the blower and the room to be conditioned.—C.E.N.

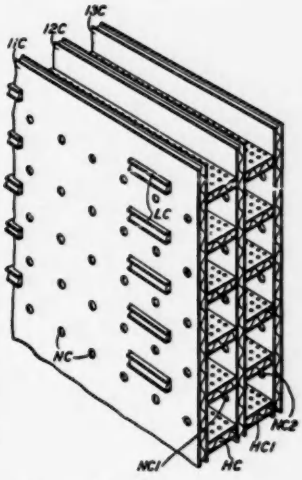


2,308,827

2.9 ACOUSTIC WAVE FILTER PANEL

Charles D. Richard, assignor to Bell Telephone Laboratories, Incorporated.
January 19, 1943, 9 Claims (Cl. 181–33).

The construction of an acoustic wave filter panel is described which utilizes the theory described in G. W. Stewart's patent 1,692,317. Examples of applications are auditoriums, telephone booths, airplane cabins, and automobile bodies. Many of the claims refer to corrugated cardboard elements—some of which are perforated—assembled to form the proper acoustic impedances. Claims for this composite structure are economy of manufacture, ease of installation, and efficient operation.—C.E.N.

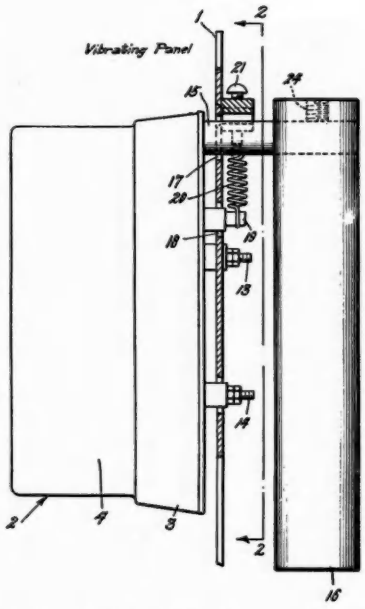


2,311,396

2.11 VIBRATION-FREE MOUNTING

Forrest H. Judkins, assignor to General Electric Company.
February 16, 1943, 2 Claims (Cl. 248–358).

This vibration-free mounting consists of a counterweight **16** so chosen that the assembly is balanced in sus-



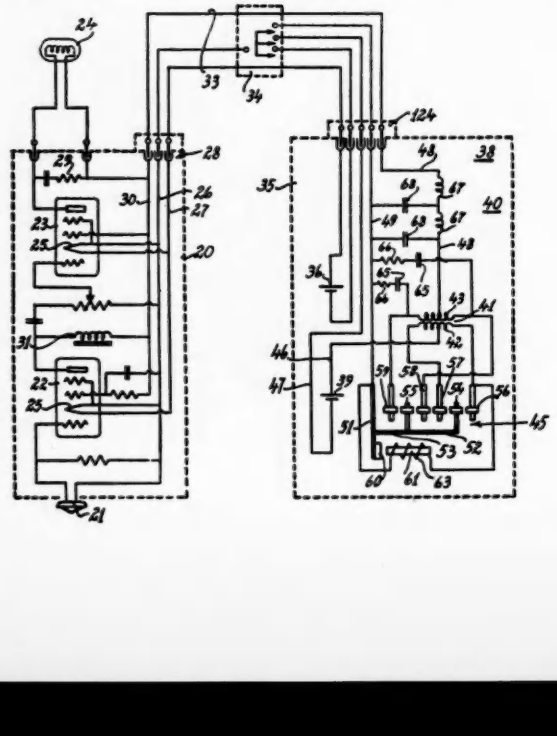
pension from two springs **20**. In this way the relay or meter in case **4** is isolated from the vibration of panel 1 without any change in external appearance.—R.W.Y.

2,308,550

4.5 AMPLIFYING HEARING AID

Harry B. Shapiro, assignor to Sonotone Corporation.
January 19, 1943, 4 Claims (Cl. 179–107).

This invention relates to a wearable vacuum tube hearing aid wherein the anode voltage instead of being supplied by the usual B battery, is supplied by a vibration type mechanical rectifier, similar to that used in auto radios. The figure shows a schematic circuit diagram of the unit. Curves shown indicate that the transformer primary current is substantially a sawtooth wave, while the secondary voltage is substantially a rectangular wave, the vibration rectifier operating to keep all the polarity unidirectional. It is stated that the entire vibratory mechanism has dimensions in inches of about $\frac{15}{16}\times\frac{5}{8}\times\frac{1}{2}$.—L.W.S.

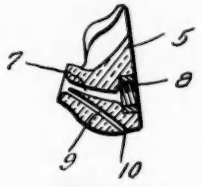


2,312,534

4.5 ACOUSTIC DEVICE

Henry D. Fiene.
March 2, 1943, 2 Claims (Cl. 181–23).

This ear plug is intended for the attachment of a hearing aid receiver, which is provided with an additional passage for ventilating the ear canal.—L.W.S.

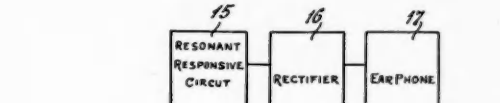


2,319,627

4.5 SYSTEM AND APPARATUS FOR SOUND RECEPTION

Sol Perlman, assignor to Hubert J. La Joie.
May 18, 1943, 10 Claims (Cl. 179–107).

In this hearing aid the energy is carried from the amplifier to the receiver in the ear by radio transmission through the body instead of the usual wire connection.



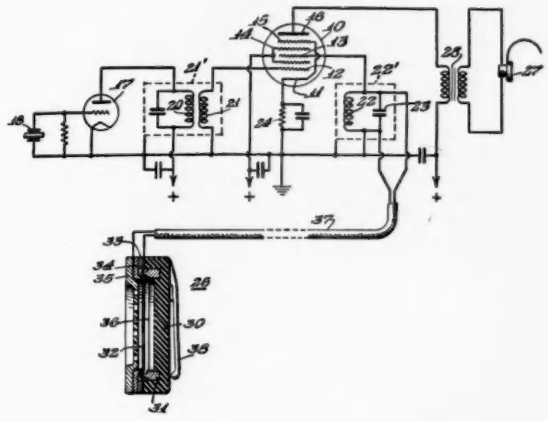
The figure shows a block schematic of the device. It is contemplated that all of the receiver elements be housed within an insertion type earphone.—L.W.S.

2,321,370

4.5 HEARING AID SYSTEM

William Dubilier, assignor to Patents Research Corporation.
June 8, 1943, 3 Claims (Cl. 179–107).

In this wearable vacuum-tube hearing aid a condenser microphone is utilized to phase modulate one of the grids in a tube of the pentagrid converter type. One of three embodiments disclosed is shown in the figure.—L.W.S.

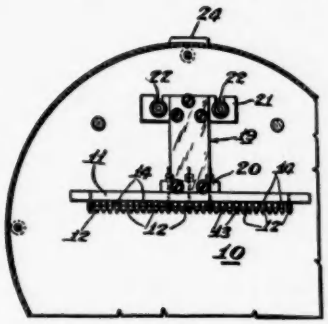


2,303,234

5.7 VIBRATORY INSTRUMENT

Gerhard W. Schwarzkopf and Thomas Barclay Whitson, assignors to James G. Biddle Company.
November 24, 1942, 13 Claims (Cl. 73–51).

"In order to render the operation of the Frahm instrument more sensitive, and to cause it to operate satisfactorily where the originating vibrations in the machine under test are of small amplitude, as in measuring speed or rates of vibration in modern smooth-running machines, the present invention contemplates a plurality of sympathetic or resonantly-vibrating elements mounted mechanically one upon the other in such a manner that the resonant vibration of the first element is amplified in the succeeding element, and so on until the amplitude of vibration induced in the set of tuned reeds, which constitutes the final element of the series, is sufficient for satisfactory visual observation." Member **19**, which is broadly resonant in the frequency range covered by vibrators **13**, is such an intermediate element.—R.W.Y.



2,320,080

5.7 PIEZOELECTRIC CRYSTAL ELEMENT

Stuart C. Hight, assignor to Bell Telephone Laboratories, Incorporated.
May 25, 1943, 13 Claims (Cl. 171–327).

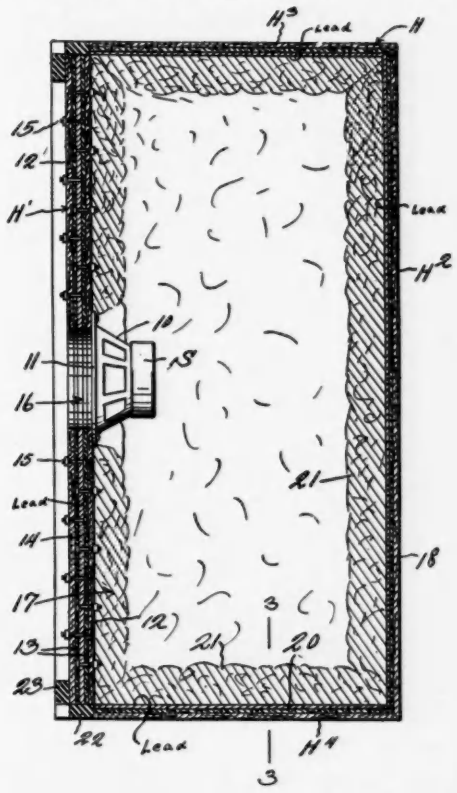
It is disclosed in this patent that piezoelectric elements such as quartz may be artificially aged by boiling them in strong sulphuric or chromic acid. This diminishes the frequency drift which is ordinarily experienced when such elements are first put into service as standard frequency oscillators.—R.W.Y.

2,315,896

5.8 RADIO SPEAKER UNIT SUPPORT

Ellsworth O. Dumas.
April 6, 1943, 6, Claims (Cl. 181–31).

The use of layers of felt paper, lead, and rock wool to make the speaker cabinet of this invention affords freedom from vibration of the cabinet, it is claimed.—V.S.



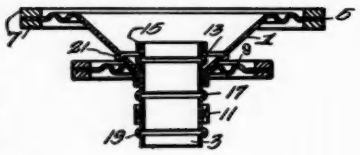
2,318,517

5.8 LOUDSPEAKER

Harry F. Olson, assignor to Radio Corporation of America.
May 4, 1943, 15 Claims (Cl. 179–115.5).

The high frequency response of the loudspeaker described in this invention is controlled by mass and resistance

mechanical elements stiffness coupled to the driving coil. Either band elimination or low pass filter effects may be obtained, it is claimed.—V.S.

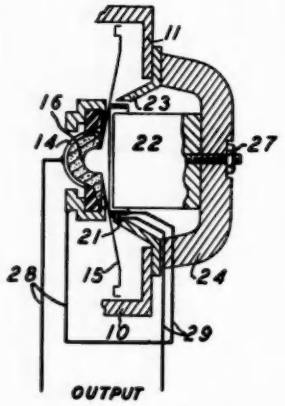


2,314,938

5.9 SIGNAL TRANSLATING DEVICE

James R. Haynes, assignor to Bell Telephone Laboratories, Incorporated.
March 30, 1943, 4 Claims (Cl. 179–122).

Carbon-granule transmitter mechanically coupled to an electro-dynamic transducer. Carbon electrodes are connected in series with the moving coil in such a manner that



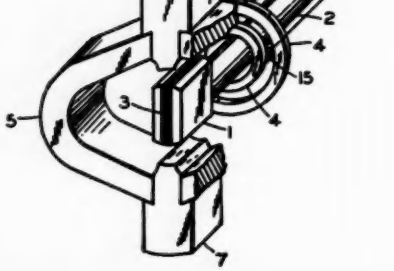
the change in current produced by the motion of the carbon electrode produces a force in the moving coil which tends to oppose the motion. It is stated that the resulting "inverse feedback" action improves linearity of the carbon device.—B.B.B.

2,299,081

5.9 VIBRATION MEASURING APPARATUS

Charles S. Draper, assignor to Research Corporation.
October 20, 1942, 7 Claims (Cl. 171–209).

Pick-up for detecting torsional vibrations in a rotating shaft. Coil **3** is coupled to and rotates with the shaft.



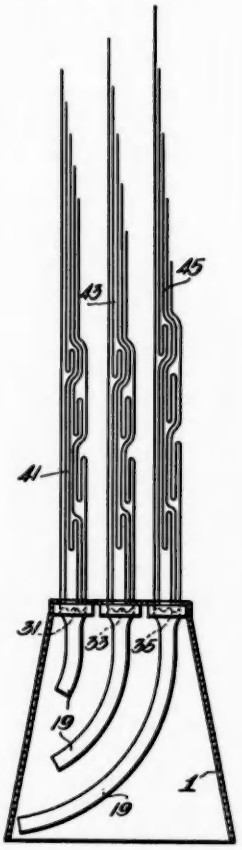
Magnetic structure **5** is coupled to the coil through a weak spring (not shown) and hence it also rotates, with uniform motion. Voltage generated in the coil is proportional to the torsional vibration velocity of coil, with respect to the magnetic structure. Connection to receiver is made through slip rings.—B.B.B.

2,299,342

5.9 ELECTROACOUSTICAL APPARATUS

Harry F. Olson, assignor to Radio Corporation of America.
October 20, 1942, 11 Claims (Cl. 179–121).

Describes a microphone consisting of a plurality of pipes of equal length and coupled at one end into a resistance terminated ribbon **5.** The pipes are provided with progressively increasing folds **10, 12, 14,** and **16** so that the open ends of the pipes are equally spaced in the vertical line.



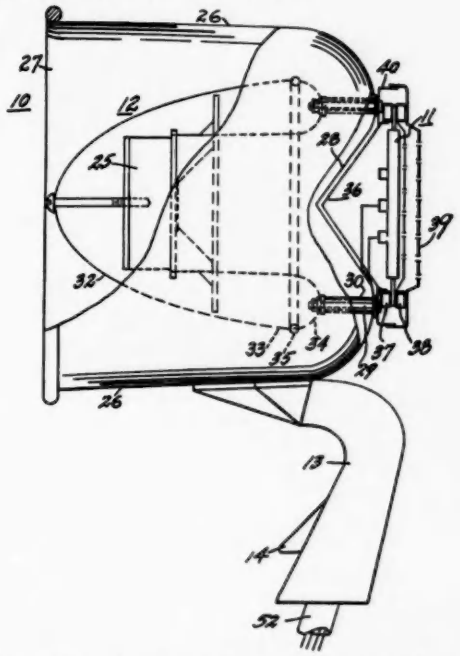
Sounds arriving in the horizontal plane reach the open ends of pipes (and hence the ribbon) concurrently. Sounds arriving from other directions arrive at open ends of pipes out of phase and tend to cancel out. Directional response pattern (throughout a range of frequencies) is toroid-like. To obtain equal directional pattern at all frequencies, several such systems of various dimensions are used in conjunction with frequency dividing networks.

Instead of using a plurality of tubes, a plurality of microphone elements may be used in proper spatial arrangement.—B.B.B.

2,314,108

5.13 ELECTRIC POWER MEGAPHONE SYSTEM

Ralph Silverman.
March 16, 1943, 2 Claims (Cl. 179–1).



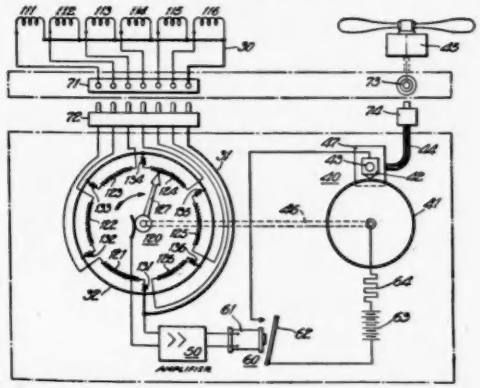
This electric megaphone employs a carbon microphone, dynamic speaker and reflexed horn in a compact combination.—V.S.

Re. 22,293

5.15 SYSTEM FOR RECORDING A PLURALITY OF MEASURING MAGNITUDES

George Keinath.
March 23, 1943, 15 Claims (Cl. 73–51).

A primary object of the device is to provide a means for recording the electrical output of vibration pick-ups **111** to **116** which are attached to various parts of an airplane. The drum **41** and the contact arm **127** are rotated in synchronism with the engine **45.** The drum may be coated with an electrochemical paper against which bears the stylus **42** which is carried along the drum by a lead screw **43.** A fraction of the voltage from pick-up **114,** for example, is delivered to amplifier **50,** its magnitude depending upon the position of the contact arm **127.** When this fraction becomes great enough relay **60** closes, thereby causing a line to be marked on the sensitive paper, whose length is thus a function of the voltage delivered by the pick-up. The resistances **124** may be tapped for linear or logarithmic steps. When the pick-ups are permanently installed at the critical points in the airplane a routine check can be made quickly by connecting the recording device through a multi-terminal plug and the flexible shaft **44.**—R.W.Y.

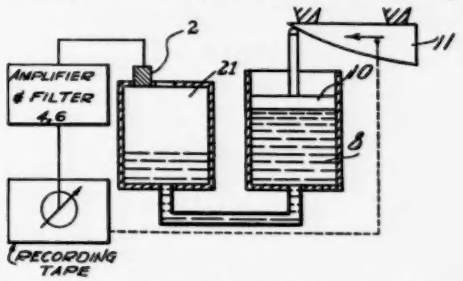


2,310,783

5.15 MEASURING DEVICE

Johann-Georg Helmbold; vested in the Alien Property Custodian.
February 9, 1943, 6 Claims (Cl. 181–0.5).

In measuring the individual components of the acoustic spectrum of sounds of low intensity, the noise inherent in the electrical system often fixes the lower limit of measurement. One way to circumvent this difficulty is to increase the sensitivity of the microphone. As disclosed in this patent



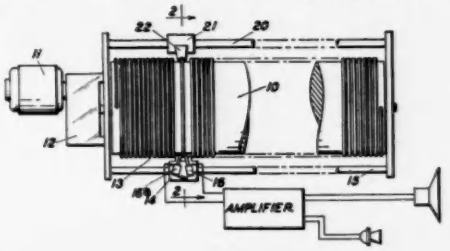
the sound sensitive element **2** is placed in an automatically tuned resonator, by which the acoustic signal is increased at the desired frequency. In one embodiment of the invention illustrated in the figure, a cam **11** is used to adjust the level of water in resonator **21.** A continuous frequency analysis may thus be made when the recording tape is synchronized with the same mechanism. The patent also discloses other forms of adjustable resonators.—R.W.Y.

2,293,229

5.16 METHODS AND MEANS FOR RECORDING SOUND

Joseph B. Walker.
August 18, 1942, 20 Claims (Cl. 179–100.2).

The conventional forms of magnetic tape recording machines use either loops of tape or spools which must be



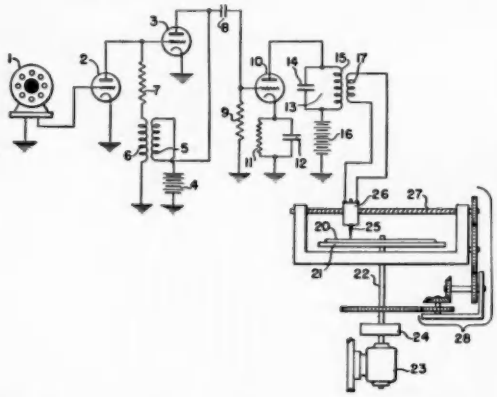
rewound. In the device disclosed in this patent the tape is wound edgewise on a drum **10** and the recording and reproducing head **16** is capable of picking up any turn on the coil by aid of the knifelike guide members below the pick-up. One object of this invention is thus to make magnetic tape recording adaptable to the dictating machine field. The relative merits of several different cross-sectional shapes of the magnetic tape are discussed in the disclosure. —L.W.S.

2,304,633

5.16 ELECTRIC RECORDING AND REPRODUCING SYSTEM

Philo T. Farnsworth, assignor to Farnsworth Television and Radio Corporation.
December 8, 1942, 13 Claims (Cl. 179–100.4).

Frequency modulation system of phonograph reproduction, in which the recording is engraved with a carrier frequency of 15,000–20,000 c.p.c., and which is frequency



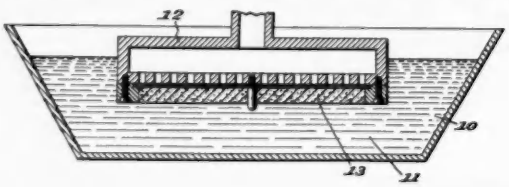
modulated in accordance with the audiofrequency signals. The reproducing pick-up is connected to a demodulation circuit. Elimination of background noise is stated.—B.B.B.

2,310,998

5.16 SOUND RECORD AND METHOD OF MAKING THE SAME

Edward E. Sawyer, assignor to The Canal National Bank of Portland.
February 16, 1943, 4 Claims (Cl. 18–48.5).

This invention describes a method of manufacturing phonograph records from resin-bearing fibrous materials. The inventor states that ordinary records manufactured from laminated paper and boards as a base are not uniform and have a tendency to warp due to a decided parallel grain structure. To overcome this difficulty it is proposed that the blank be made by immersing foraminous suction dies **12** in aqueous pulp mixtures containing insoluble, uncured, synthetic resin and fibers. The blank in which the fibers are well-felted is then dried and is eventually cured in the usual pressing process. A laminated record may be made by combining an inner core having a high percentage of fibers with outer layers containing a high percentage of resin.—L.W.S.

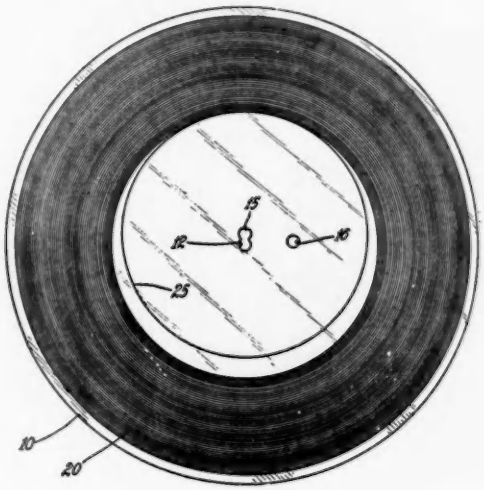


2,309,276

5.16 SOUND RECORD

Vernon L. Roberts, assignor to of one-half to Richard H. Wann.
January 26, –943, 5 Claims (Cl. 274–42).

This invention relates to a means of producing an eccentric groove in a home recording blank by means of an off-center hole **15** in the disk.—L.W.S.

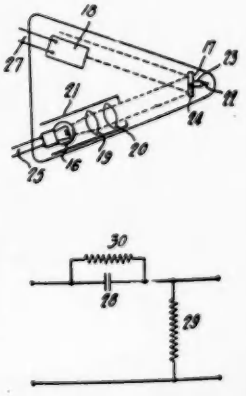


2,316,113

5.16 PHOTOELECTRIC PHONOGRAPH

Milton L. Thompson and Elmer O. Thompson, assignors to Philco Radio and Television Corporation.
April 6, 1943, 2 Claims (Cl. 179–100.4).

Photoelectric phonograph pick-up comprising a source of light **16**, a photoelectric cell **18**, a mirror adapted to be rotated by a phonograph stylus for the purpose of varying the amount of illumination falling on the cell in accordance with displacement of the stylus, and an electrical network (lower figure) providing correct reproduction of sound from commercial "constant velocity" recordings.—B.B.B.

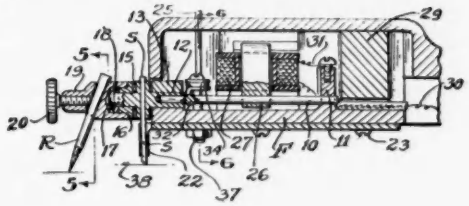


2,318,308

5.16 STYLUS HEAD FOR RECORDING AND REPRODUCING SOUND RECORDS

Edward Robert Harris, assignor to Isabelle Russell Harris.
May 4, 1943, 3 Claims (Cl. 179–100.41).

This invention relates to a combination electromagnetic recording and reproducing device in which a short cutting stylus ***S*** is permanently positioned, whereas a longer reproducing stylus ***R*** is capable of being rotated. When ***R*** is held in playing position by the friction collar **15** the recording stylus is lifted out of contact with the record.—L.W.S.

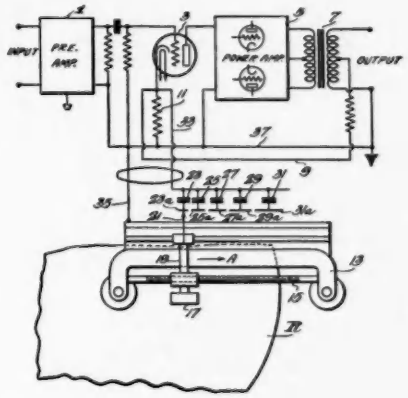


2,320,429

5.16 SIGNAL RECORDING AND REPRODUCING SYSTEM

Harold J. Hasbrouck, Jr., assignor to Radio Corporation of America.
June 1, 1943, 2 Claims (Cl. 179–100.4).

This invention discloses a means of equalizing for the playback loss in 33⅓ r.p.m. recordings by increasing the amount of negative feedback at high frequency in the recording amplifier as the cutter moves outward toward the edge of the disk.—L.W.S.

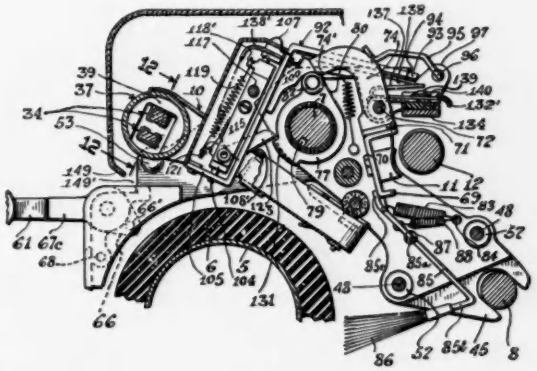


2,320,572

5.16 PHONOGRAPH

Charles W. Dann, assignor to Thomas A. Edison, Incorporated.
June 1, 1943, 19 Claims (Cl. 179–100.4).

This invention relates to a streamlined wax cylinder type of dictating machine. A Rochelle salt crystal "bimorph" 23 of the bender type is used as the transducer



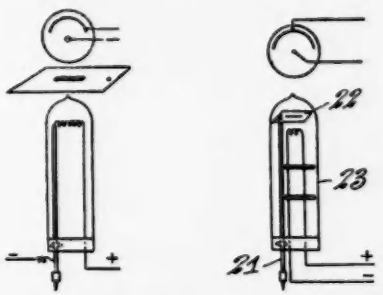
element for both recording and reproduction. The recording stylus **29** and reproducing stylus **30** are connected to the crystal element by means of Lucite holder **28.** Undesired resonance and vibration of the transducer assembly are mitigated by the vibration damper **34.** Lever **61** serves to shift the device to either recording or reproducing positions and thus affords a simple means for quickly playing back any portion of the record. When in the recording or reproducing position, half-nut **70** engages lead screw **12,** thus transporting the carriage along the cylinder.—L.W.S.

2,320,879

5.16 PHONOGRAPH REPRODUCING APPARATUS

Oran T. McIlvaine.
June 1, 1943, 6 Claims (Cl. 179–100.41).

This invention relates to a photoelectric phonograph reproducer whose object is "to obtain much better fidelity, and substantially eliminate needle scratch without sacrificing any of the musical range." This is to be accomplished



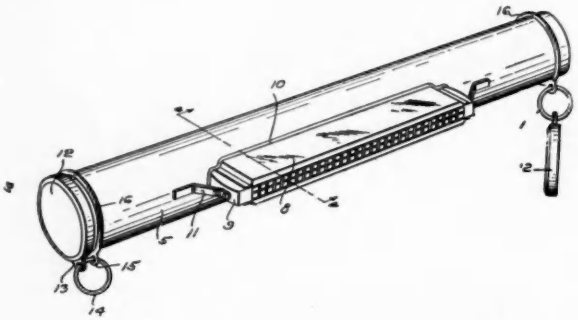
by controlling the light falling on the photoelectric cell directly by means of the reproducing stylus. Two of the five embodiments are illustrated herewith. Claims are limited to mechanisms in which the needle-actuated light valve is associated with the light envelope.—L.W.S.

2,309,406

6.1 MUSICAL INSTRUMENT

Patrick McAuliffe.
January 26, 1943, 4 Claims (Cl. 84–378).

In accordance with this invention a tube **5** is slotted to receive a harmonica **8,** so as to modify the tone produced by



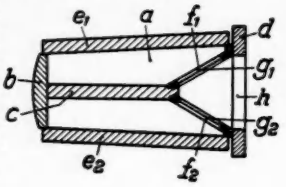
the latter. Caps **12** may be attached to the ends of the tube to afford additional changes in tone quality.—R.W.Y.

2,310,908

6.1 REED HOLDER

Walter Neuerburg; vested in the Alien Property Custodian.
February 9, 1943, 2 Claims (Cl. 84–376).

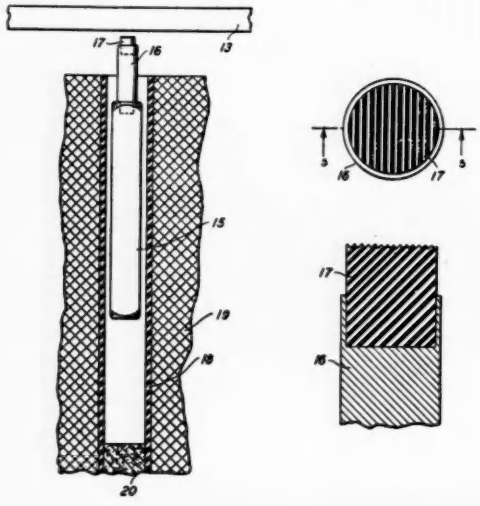
It is common practice in accordions to use slide valves to control sets of reeds, which move lengthwise of the instrument and in a plane essentially perpendicular to the reed blocks e_1 and e_2. Thus to increase the openings necessitates lengthening the instrument. This patent disclosed a way of increasing the size of these ports without changing the external dimensions, by so placing the slides that their intersections with the plane of the figure appear at f_1 and f_2. The opening h may thus be made larger than was previously possible because the guard space for the slide valves is no longer needed.—R.W.Y.



2,307,989

6.2 SOUND SIGNAL

Kline E. Bower, assignor to Bell Telephone Laboratories, Incorporated.
January 12, 1943, 7 Claims (Cl. 116–148).



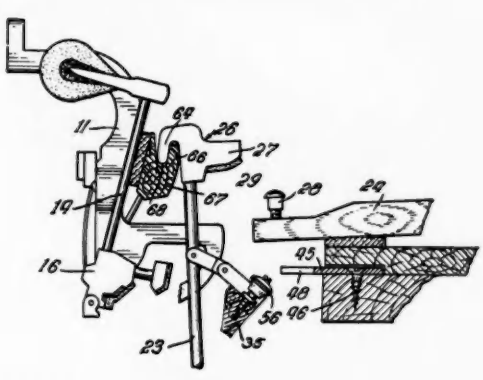
This patent discloses a novel corrugated tip **17** for use on the end of the striker in an electrically operated chime. The solenoid **19** when energized attracts the plunger **15** upward so that the tip **17** makes momentary contact with the chime bar **13.** It is claimed that the tip may be made of a fairly tough material such as to have long life and to produce a strong signal, and that the corrugation removes the unpleasant clang which would otherwise be associated with the impact.—R.W.Y.

Re. 22,247

6.6 PIANO ACTION

William G. Betz, assignor to Pratt, Read and Company.
January 12, 1943, 15 Claims (Cl. 84–240).

"One of the principal advantages of this invention is the provision of an action which is transportable, and assembled in a piano as a single self-contained unit, and which may be connected with the keys merely by insertion of the keys into the piano, without individual handling of the abstracts in the action." When it is desired to remove the action from the piano the rail **35,** which carries a pivoted guide unit for each abstract **19,** is detached from the fingers **48** on the keybed by loosening the knurled nuts **56.** By lifting this rail **35** all the abstracts are hooked to the special guide flange **66** by means of the hooked portion **64** with which each abstract is equipped. Thus there are no dangling abstracts to interfere with handling the action.—R.W.Y.

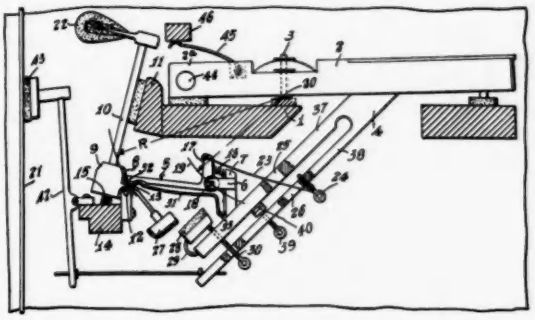


2,309,278

6.6 PIANO ACTION

Carl Schulze.
January 26, 1943, 8 Claims (Cl. 84–240).

This action is particularly adapted to the small piano by virtue of the short distance required between the forward end of the key and the string. The key **2** carries the jack **5** with it as a rigid unit so that the tip of the jack **32** rotates in an arc of radius ***R.*** Thus, as the key is depressed the jack is gradually lifted off the driving shoulder **8** on the hammer butt **9.** This eliminates the sudden resistance which is developed by the setoff in the ordinary action. Rapid repetition is assisted by spring **31** which impedes the return of the hammer to its rest position. This allows



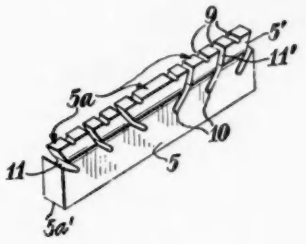
the jack to drop back into position on the rest shoulder **13**, in readiness for the repeat stroke, when the key has been allowed to rise only a short distance.—R.W.Y.

2,309,082

6.7 GUITAR AND GUITAR NUT

William J. Smith and George H. Smith.
January 26, 1943, 4 Claims (Cl. 84–314).

When guitars are played in the so-called Hawaiian style the strings are elevated at some distance above the fingerboard and are stopped with a bar. For Spanish style of execution the strings are pressed against the frets directly by the fingers, so that the nut need elevate the strings only slightly. This patent discloses a nut which facilitates a quick shift by the player from one kind of support to the other. Since the channels **11** lead to notches **10** which are directly below notches **9**, the lateral positions of the strings remain the same regardless of which level is employed.—R.W.Y.

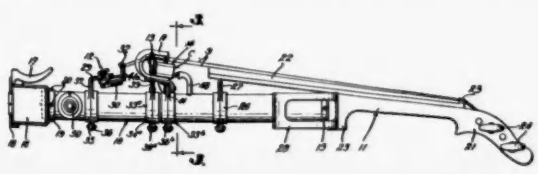


2,310,199

6.7 STRINGED MUSICAL INSTRUMENT

George D. Beauchamp.
February 9, 1943, 4 Claims (Cl. 84–1.15).

"The improved electrical musical instrument of the present invention may be said to comprise, generally, an elongate body **10**, a neck **11** on the body, a tail-piece **12** adjustable along the body, strings ***S*** anchored to the tailpiece **12** and stretched across the body **10** and the neck **11**, a bridge **13** for the strings ***S*** adjustable along the body **10** and operable to convert vibrations of the strings ***S*** into modulations or pulsations into an electrical amplifying and reproducing circuit." Ease of adjustment and simplicity of manufacture are stressed. The rest **28** is to assist the musician in orienting his hand.—R.W.Y.

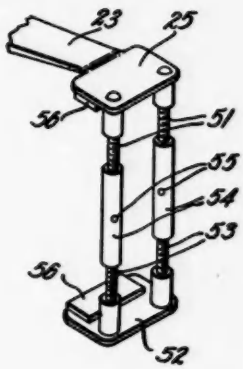


2,310,606

6.7 MUSICAL INSTRUMENT

Paul M. Barth.
February 9, 1943, 9 Claims (Cl. 84–1.16).

"An object of this invention is to provide means for mounting or providing an electrical pick-up on a stringed instrument such as a violin, guitar, or the like, without in any way affecting the resonance or tonal qualities of the instrument, thus allowing the instrument to be played either with or without the benefit of the pick-up means." The structure consists of a transverse bridge which passes under the strings and which carries the pick-up proper. This bridge is attached by two clamps such as the one illustrated in the figure. Since the only points of attachment are at the sides of the instrument, the sound board is left free to vibrate in the event the instrument is to be played without electrical amplification.—R.W.Y.

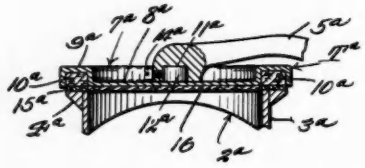


2,311,167

6.8 TAMPION

Charles Bird Gage.
February 16, 1943, 3 Claims (Cl. 84–385).

One of the objects of this invention is to provide a pad cup with an annular pad for an instrument, such as a saxophone, having a mechanical joint intended to facilitate the quick replacement of the unit. A reason advanced for the need for such replacement is that for one style of playing a soft tone is desirable which can be had by the use of the padding **16** covering the entire inner surface of the pad cup. When a more strident tone is desired it is to be obtained by replacing the pad cups with others in which only an annular pad **15*a*** is used thereby leaving the whole central area, exposed to the vibrating air column, of bare



metal. An additional footing **10a**, as of cork, is employed to aid in producing the air tight seal. It would appear prohibitive to manufacture these parts with sufficient precision that the player could interchange them at will and still have the pads cover properly.—R.W.Y.

2,310,429

6.9 ELECTRICAL MUSICAL INSTRUMENT

John M. Hanert, assignor to Hammond Instrument Company.
February 9, 1943, 20 Claims (Cl. 84–1.25).

"It is the main object of this invention to provide means whereby, with a single keyboard, the musician may produce a plurality of octave related tones which in themselves emit their sound from spatially separated electro-acoustic translating systems, and may also be individually controlled as to dynamic envelope and quality of tone." To do this the inventor provides several separate channels each complete with tone modifying circuits and loudspeaker. With but two such channels:

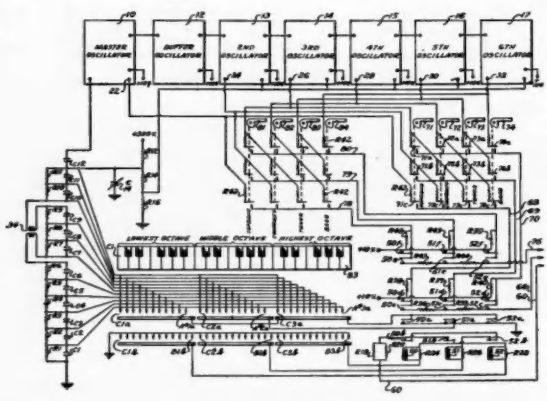
"(1) The pitch may be adjusted at will, in four octaves, by operation of the register controls **71** to **74** and **81** to **84**. . . .

"(2) By selective operation of switches, the harmonic development of the tones may be altered to a pronounced extent. . . .

"(3) By adjustment of the tone control meshes, the player may selectively determine the resonances and the general brightness of mellowness of the tones.

"(4) . . . the player may selectively determine whether the tone shall be of decided percussion, of moderate percussion, or of slow attack organ-like intensity envelopes. . . .

"(5) . . . the relative volumes of the outputs of the two channels may be controlled.



"(6) . . . the musician may selectively impart a vibrato effect to the outputs of either or both channels." —R.W.Y.

2,311,399

6.9 ELECTRIC PIANO

Walter B. La Chicotte, Jr., assignor to Radio Corporation of America.
February 16, 1943, 2 Claims (Cl. 84–1.01).

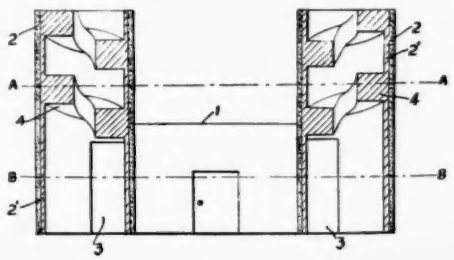
In order that the player of an electrically amplified piano may have control over the direction in which the sound of his instrument is concentrated, a number of loudspeakers and loudspeaker passages are provided whereby a selection may be made either by electrical switching or the operation of shutters. For example, these controls may be set so that the bass tones are emitted at 11 and the high frequencies at 12 and also through banks of small speakers at 13, 14, 15, and back of the piano.—R.W.Y.

Serial No. 402,549

7.6 SOUND ARRESTER IN THE VENTILATOR OF SOUND-ARRESTING ROOM

Masaichi Tominaga; vested in the Alien Property Custodian.
May 18, 1943.

In a room ventilator cylindrical ducts are used with acoustically treated walls and acoustically treated spirals. This construction increases the length of travel of the air over the sound absorbing material thus increasing the attenuation of the noise.—C.E.N.

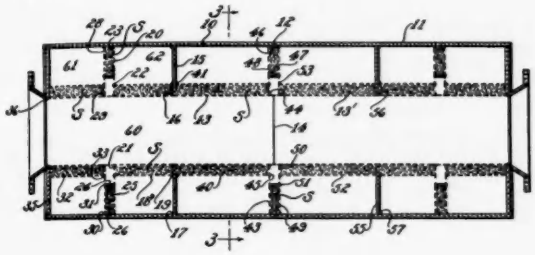


2,311,676

7.7 SILENCER

Hiram Hamilton Maxim, assignor to The Maxim Silencer Company.
February 23, 1943, 5 Claims (Cl. 181–48).

This patent describes a silencer construction for use on large pipe sizes in which the acoustic coupling to each resonator is through a layer of sound absorbing material in parallel with a localized unrestricted opening. The resonators have pervious partitions of sound absorbing material. —C.E.N.

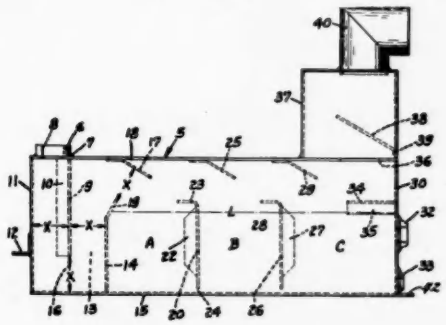


2,312,242

7.7 MUFFLER

Elmer J. Dunham, assignor to Clark Equipment Company.
February 23, 1943, 4 Claims (Cl. 181–49).

A muffler intended particularly to be used on trucks and tractors in fields where there is danger of starting fires by exhaust sparks. The gas enters the muffler and flows through a dry turning chamber. Then it is deflected by baffle plates towards the surface of several chambers or compartments filled with water. Such action is claimed to quench the sparks in the exhaust gases. Before leaving the muffler the gas flows into an expansion chamber which reduces the velocity. Claim is also made that this causes recondensation of the water vapor so that replacing of the water is necessary only at infrequent intervals.—C.E.N.



2,312,399

7.7 COOLING EXHAUST CONDUITS

Anselm Franz; vested in the Alien Property Custodian.
March 2, 1943, 12 Claims (Cl. 60–35.6).

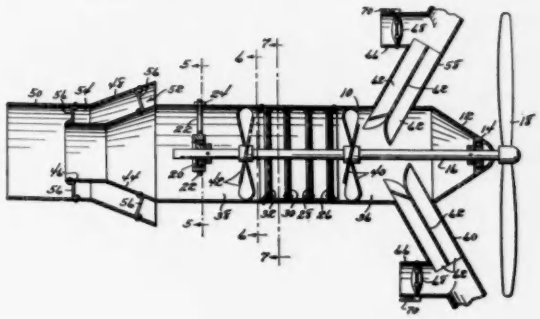
A cowling designed for use on an airplane engine is made in streamlined form. The leading edge has holes through which cooling air enters and circulates around each individual exhaust stack. This cooling air leaves through ports axial to the exhaust ports. No claims are made for silencing.—C.E.N.

2,313,244

7.7 MUFFLER

William C. Jones.
March 9, 1943, 8 Claims (Cl. 181–64).

In an airplane a propellor driven fan is proposed to create a region of low pressure within the muffler. The engine exhausts into this low pressure chamber and thereby reduces back pressure on the engine.—C.E.N.



2,315,305

7.7 MUFFLER

Harold E. Van Voorhees.
March 30, 1943, 10 Claims (Cl. 181–56).

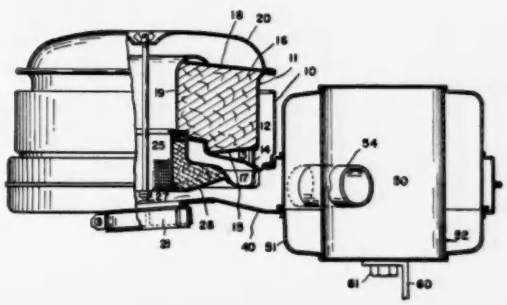
In this muffler design the exhaust gas passes through a perforated tube and is deflected by baffles of particular shapes designed to increase their efficiency.—C.E.N.

2,316,527

7.7 COMBINED AIR CLEANER AND SILENCER

Merritt A. Mieras, assignor to Industrial Wire Cloth Products Company.
April 13, 1943, 3 Claims (Cl. 183–1).

A combined air cleaner and silencer consisting of separate silencer and cleaner chambers connected laterally by a tube or tubes. Advantages claimed are reduction of height and improved accuracy and flexibility of tuning chambers. —C.E.N.

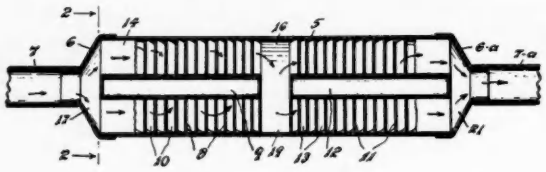


2,317,246

7.7 MUFFLER

Adolph G. Bergmann.
April 20, 1943, 8 Claims (Cl. 181–66).

A muffler formed by spiral fins inside the outer shell is described. These fins form a multiplicity of comparatively small parallel paths for the exhaust gas.—C.E.N.

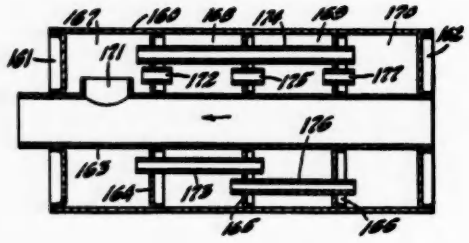


2,323,955

7.7 RESONANCE UNIT

Ernest E. Wilson, assignor to General Motors Corporation.
July 13, 1943, 33 Claims (Cl. 181–48).

This patent refers to a resonance unit made up of a number of resonators connected to the main conduit or to each other in order to attenuate the objectionable noises in the main conduit. Specific reference is made in the description to the application to the intake and exhaust systems of internal combustion engines such as automotive



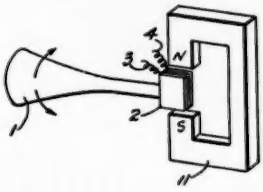
engines. In the acoustic design of these units a number of elements are used including simple and compound resonators and sound absorbing materials. In the text is included a description of the method for designing the particular silencer for a given application. This includes both mathematical and "cut-and-try" operations.—C.E.N.

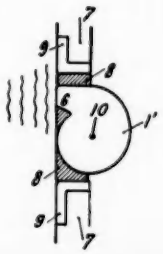
2,313,290

10.3 APPARATUS FOR TRANSFORMING OSCILLATIONS

Joseph Bethenod and Yves Rocard; vested in the Alien Property Custodian.
March 9, 1943, 6 Claims (Cl. 177–386).

Means for transducing ultrasonic vibrations consisting of a tapered bar **1** actuated torsionally about axis **10**. This exponential transmission line acts as a transformer, changing high mechanical impedance at the large end **1'** into low





mechanical impedance at the small end **2**, which is actuated by the electromagnetic driver **11**. Since the bar moves in torsion, the transmitting (or receiving) surface **6** is on the "side" of end **1'** which is anchored to the hull of a boat, for example, by the elastic support **8**.—B.B.B.